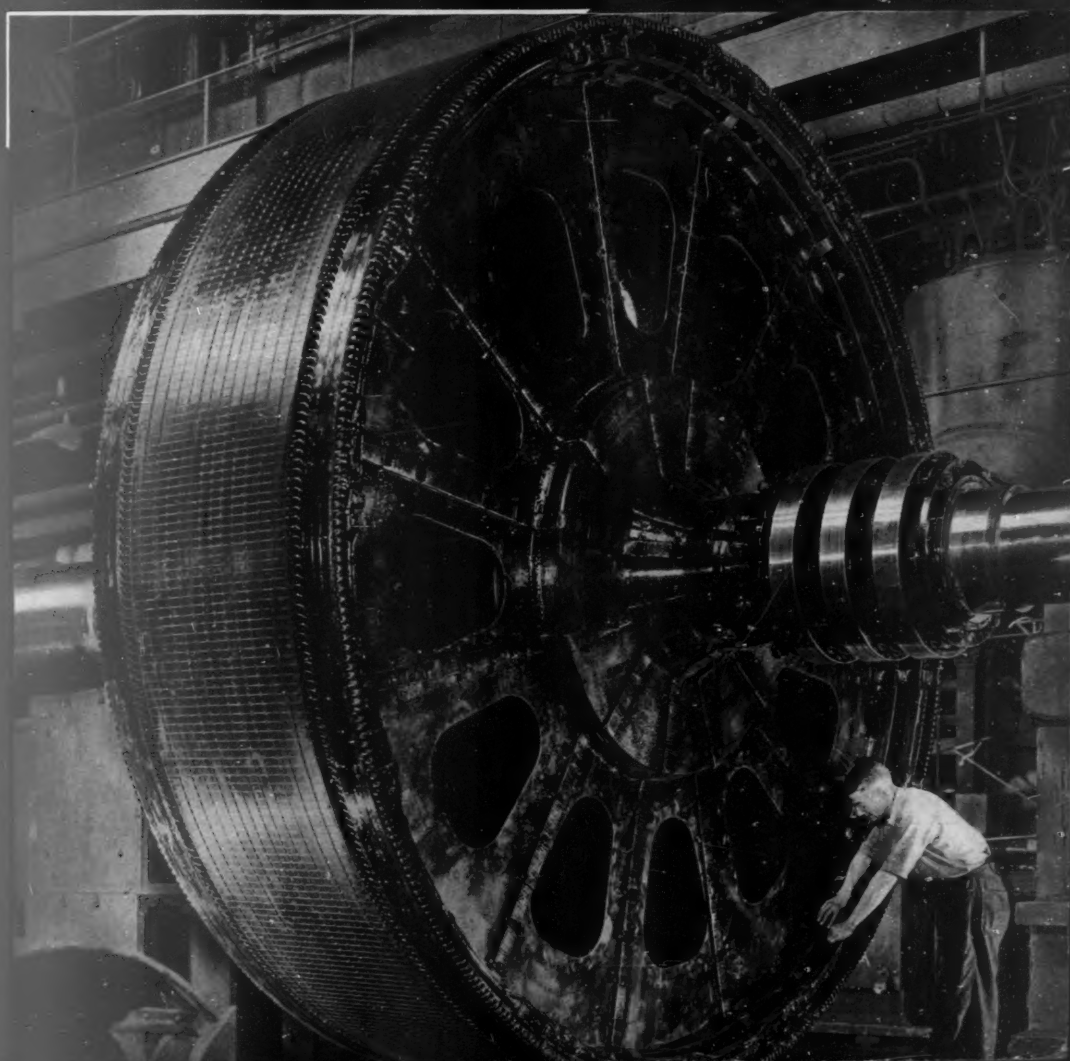
ALLIS-CHALMERS

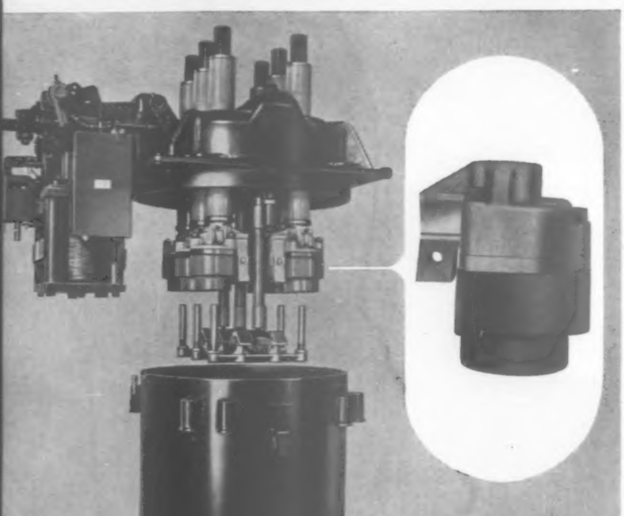
ELECTRICAL REVIEW

September • 1939



QUICK-QUENCH!

Ruptors Extinguish Arcs FAST! Their "QUICK-QUENCH" Action CUTS Oil Carbonization and Contact Deterioration to a Minimum!



CHOSEN FROM TWENTY-THREE separate and distinct designs for an interrupting device was the "Ruptor," shown here at the right. After exhaustive tests, it was developed to its present high efficiency and incorporated in oil circuit breakers, such as the one shown here.

● High interrupting capacity! Low maintenance cost! Fewer contact replacements! More hours of service between inspections!

That's what you get with Allis-Chalmers Oil Circuit Breakers with Ruptors for high voltages. For Ruptors extinguish arcs .... *in a hurry*! Their "QUICK-QUENCH" action reduces oil carbonization and contact replacement . . . eliminates high maintenance and inspection costs! You get consistent operation without constant attention.

Ruptors assure low tank pressures. They eliminate oil throw. Arc energy is kept low because interrupting arcs are exposed only to a small volume of oil. And when the circuit breaker does need service, the job is done quickly and easily. Ruptors are accessible to inspection and maintenance . . . easy to get at . . . not like other circuit breakers that take valuable time to service.

World-Wide Research Facilities

You get more "breaks" for your money when you specify Allis-Chalmers. And you get more than that. You get the benefits of Allis-Chalmers' engineering background and experience . . . the world-wide facilities that the testing laboratories of Allis-Chalmers, and of associated companies, can offer.

Find out what "QUICK-QUENCH" action can mean to you. Call the nearest Allis-Chalmers District Office. Let your Allis-Chalmers representative show you what "QUICK-QUENCHING" can do to give you higher interrupting capacities . . . and greatly reduced maintenance costs!

923

SWITCHGEAR DIVISION

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ELECTRICAL REVIEW

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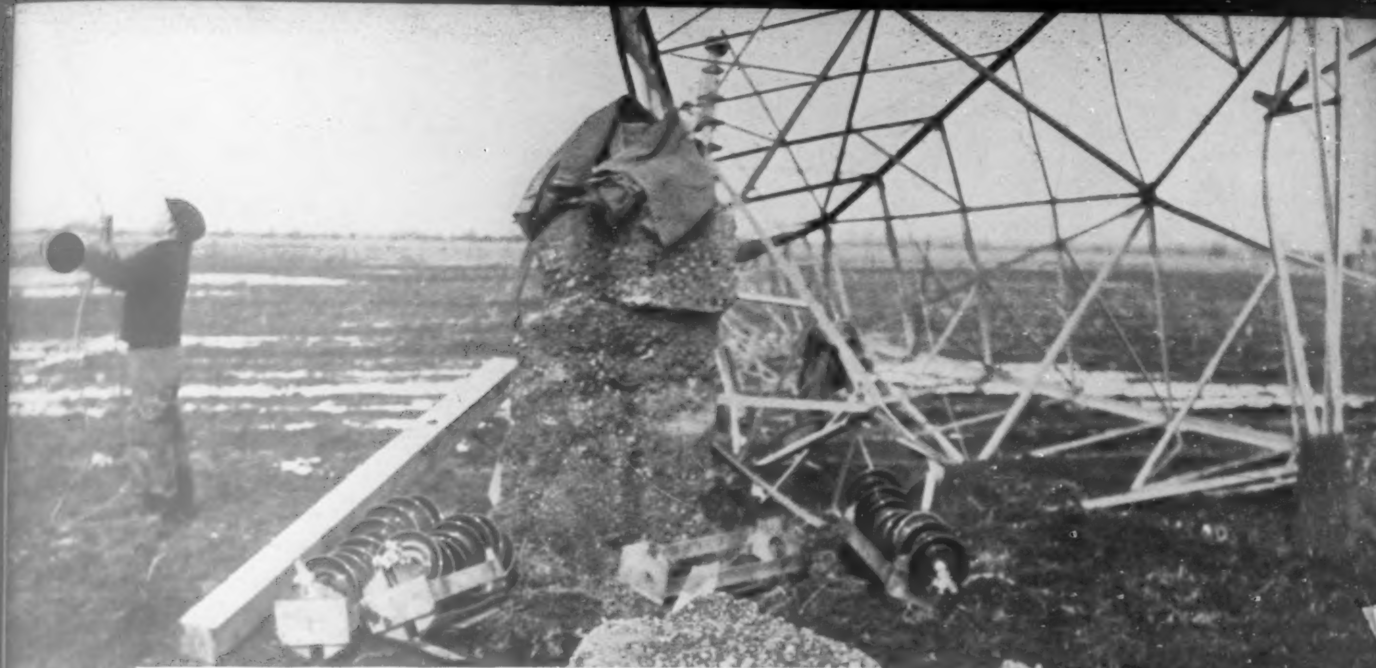


BUCKING THE STORM

• I. W. Collins, Chief Load Dispatcher

PACIFIC GAS & ELECTRIC CO. . . . SAN FRANCISCO, CALIF.

● Thirty-two years ago, in a corner of the Oakland Steam Plant, known as the Tin Castle, Mr. F. R. George founded the Load Dispatcher's Office and Dispatching System to coordinate the operation of several power systems recently combined by what would now be termed a merger. The limited communication development at that time dictated the selection of the City of Oakland, California, as the most suitable location for the office.

Following the 1906 earthquake, other systems merged with this first group, and the combination thus effected gave birth to the Pacific Gas and Electric Company. Since then, many mergers have developed a system which now extends over an area greater than any one of the 48 states except Montana, Arizona, New Mexico, California, or Texas. There are 45 switching centers (or subdispatching centers) spread out over the State of California at strategic points, from the summit of the Siskiyou on the north to the summit of the Tehachapi on the south, from the summit of the Sierra Nevadas on the east to the shoreline of the Pacific.

● AT LEFT: Permanently evacuated and air-cooled is this 100 kw, 600 volt glass tube rectifier unit, built for a southern utility.

● ABOVE: Aftermath of the storm—a 125 kv line near Rio Vista.

The activities of the Load Dispatcher's Office grew with the system. Now a minimum of two dispatchers are on duty at all times to supervise the system and to care for the immediate and future needs of our customers.

• A unique commodity

The commodity we provide is unique — it is one which is subject to ever changing demands:

It must be produced, transmitted, and distributed at the exact instant the customer demands.

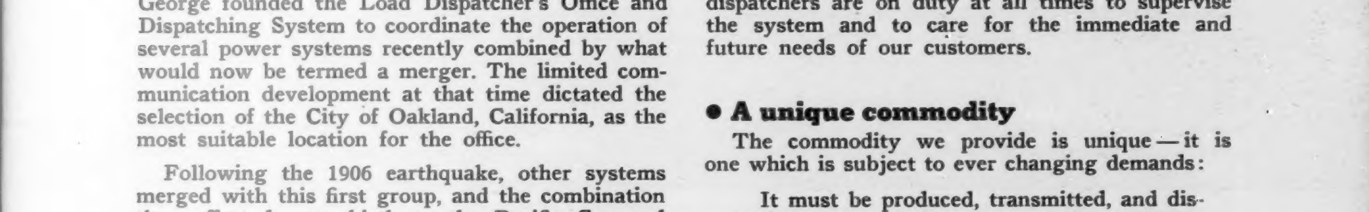
It cannot be produced and stored or held in reserve for future needs.

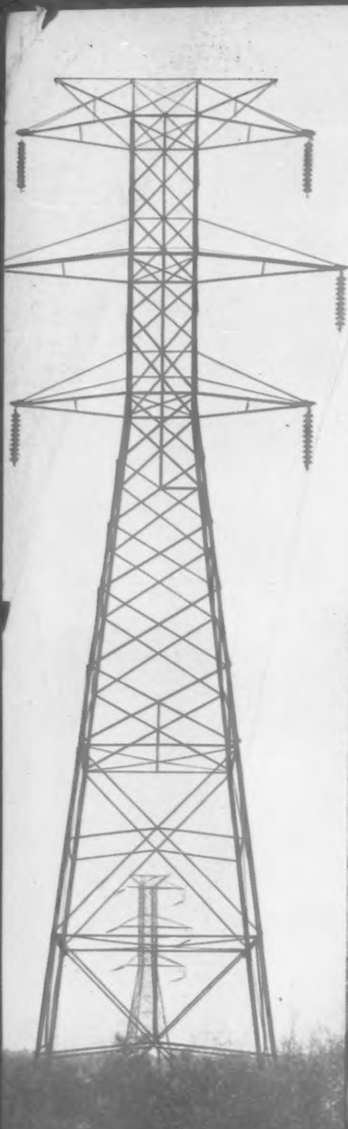
It is subject to the most exacting requirements.

It must be instantly available in sufficient quantities and cannot be produced in greater quantities than the customers require.

The load dispatchers operate the system to meet these exacting requirements.

Canals, flumes, generators, transformers, transmission and distribution lines, and other associated





● AT RIGHT: Poles lean at rakish angles after the severe storm of February, 1938.

equipment must be maintained in operation in order to provide our customers with this all-essential commodity — electric energy. The principal source of energy is from the hydro plants; and behind these are 136 storage reservoirs which, when full, contain sufficient water to supply the present total water requirements of the City of San Francisco for 46 years.

● Impending storms

To insure continuity of service, the load dispatcher maintains a close watch on weather conditions existing over the Pacific Ocean and Pacific Coast states. Information is obtained through the usual weather bureau channels and also from the airways to the north, south, and east. Barometric readings and wind directions and velocities indicate the direction and rate of travel of a storm so that ample warning is provided to meet these "battles with the elements."

● Catastrophe

The February 1938 storm was anticipated two and a half days before it reached the southern coast line. Low pressure areas, far lower than those experienced before the average storm, accompanied by extremely high winds, indicated the storm would be a "stem winder." Reserve steam and hydro generating units were prepared and placed in operation before the storm reached any section of the system. Line and maintenance crews were ready and waiting to play their part.

If you can imagine a limb broken from a tree and stripped of every leaf, every branch broken, and the main limb broken in many places, you have something resembling a bird's-eye view of

some of the transmission lines and most of the distribution system in the San Joaquin and Sacramento Valleys after the storm had passed. Structures which normally withstood excessive gales were uprooted from water-soaked ground and crumpled as though they were made of paper. Poles leaned at rakish angles or were laid flat where the storm had been most severe; others floated away.

Power houses, some of which were incapacitated in the December 1937 flood, were again flooded; and the output of the steam generating plants was limited because of low vacuum due to the storm.

• Restoration

Line crews with trucks, tractors, pole-lifting devices, barges, pile drivers, and other major emergency equipment were rushed to the centers which experienced the greatest damage. Many of these crews had to travel many roundabout miles to enter the flooded areas. Some had to use boats and pack on their backs materials wet by several days of drenching rain and wind. They worked in mud up to their hips, propped poles in various ways, waded through water to their waists, swam normally dry creeks to restring lines, ran temporary "shooflys" to restore service, retraced their path to put up poles which had fallen behind them, and performed many other disheartening tasks. For a time it appeared as though the elements had unleashed everything.

Collectors, meter readers, clerks, estimators, office workers — in fact, a large majority of our 10,000 employees — responded immediately to help re-establish service to hospitals, sanitariums, fire-fighting equipments, hotels, and other important buildings, and worked as much as two and three days and nights continuously with only a few minutes out for food. Load dispatchers, telephone operators, complaint crews, and others contacting the public, worked continuously for a week or ten days with only short rest periods after the first few days and stopped only when the emergency had passed.

In spite of the widespread damage, most of the electric service was restored to homes as flood waters receded. In many instances service was restored before people permanently re-occupied their homes. Looking back over the work, much of it being temporary or "haywire" in nature, one wonders how human effort could surmount the obstacles encountered.

• Lives in danger

Heroic action on the part of our employees while performing the sometimes difficult task of providing our customers with this commodity, electric energy, has not been uncommon. When a hurricane tore down the 11 kv line serving the Ophir Mine, six men were trapped inside the mine. One was quite aged and was suffering the first stages of pneumonia. The line crews worked feverishly against time, re-established the service, and hoisted these men to the surface none too soon.

A troubleman, during a recent flood at Gerber, was sent by the load dispatcher to open a switch. While he was completing the operation, overflow from the river made it impossible to return to his car. He took refuge in a pear tree and was later rescued by a co-worker, who had procured a boat and started a search. Upon their return, while passing a flooded home, faint cries were heard, and after chopping a hole through the roof a family was found between the ceiling and roof where they had taken refuge. Many other rescues of a similar nature were made by employees throughout the system during this same flood.

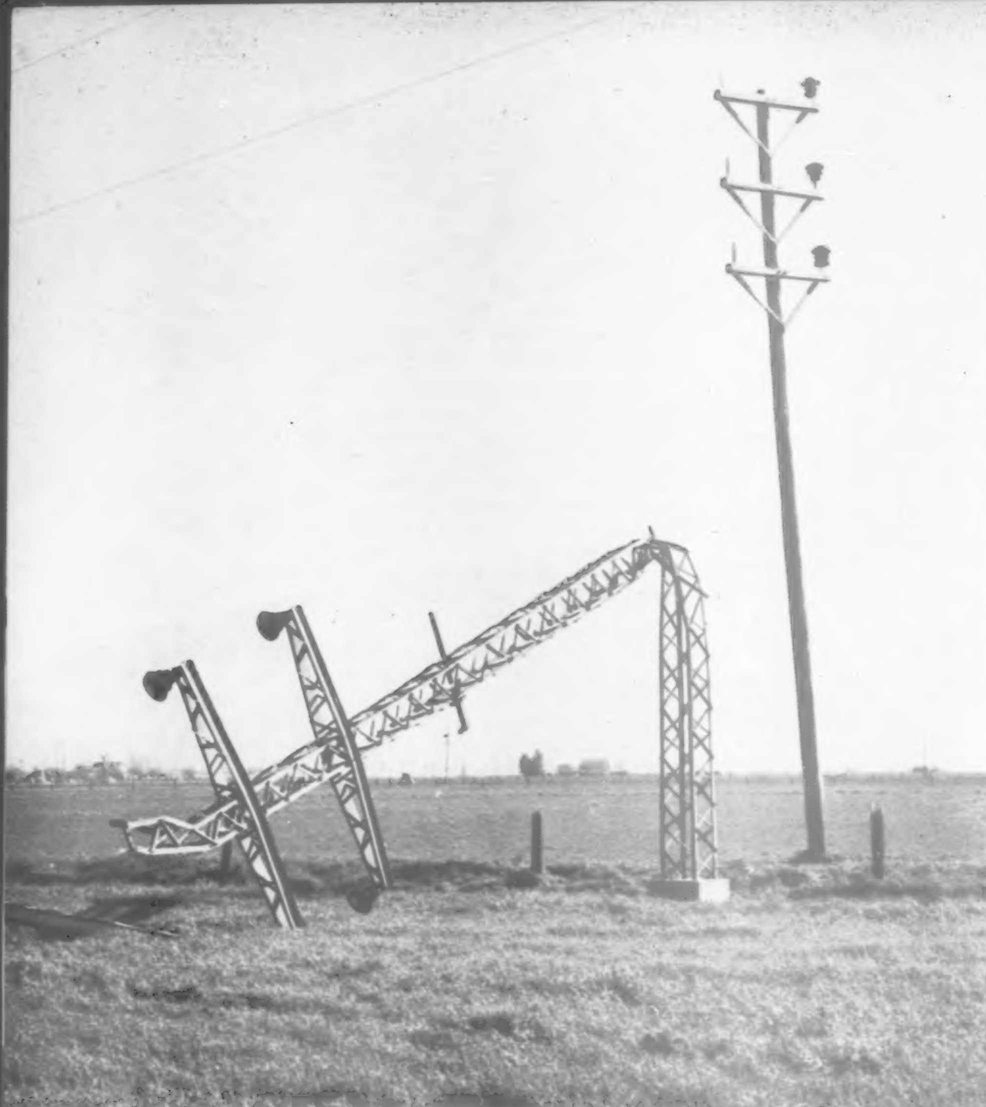
During an extremely heavy snow storm in the Sierras, a failure occurred on the line serving the Sierra Pacific Power Company at the Donner Summit. It was necessary to arrange for the rotary snow plow to precede the two men sent for switching near the Summit. They left their car at the Highway Maintenance Camp, then proceeded three-fourths of a mile on skis, over snow 20 to 22 feet deep, to the Meter Station to do the switching necessary to clear the line.

At approximately 12:30 in the morning the line crew started the repairs. At this time, in addition to the snow, a 55-mile wind was blowing, and ice had formed on the windward side of the pole to a width of several feet. The linemen had to ski to the pole, unstrap their skis, and maintain their balance on one foot while putting on their climbers, then face the storm, clasp the pole on each side (they could not possibly reach around the pole and ice, and they could not knock the ice off the entire height of the pole), and climb to the cross arm. There it was necessary to knock several feet of snow and ice from the arm and insulators, knock off the ice from the windward side of the pole, turn their backs to the storm, and fasten their safety belts around the pole. Imagine working 30 feet above the snow, being fastened to an ice-covered pole in a 55-mile gale and with sub-zero temperature. One slip or the cutting out of a spur meant a partial fall and severe cuts by the sharp ice.

• "What can we do now?"

An hour and a half later the trouble was repaired, the men were clear, and the line was restored to service. The line foreman in charge of the work called in on his portable phone, with the howling of the wind almost as loud in the transmitter as his booming voice, and, typifying the real meaning of "Pacific Service," asked, "What can we do now?"

The line crew was sent back to the tavern and to bed. The two men remained in the shelter house at the Summit Meter Station as it was unsafe to attempt to return to the highway with that gale. About three o'clock in the morning the storm had moderated slightly, with a 40-mile wind still blowing the snow around. The two men started back but veered off their course because of the wind. Contact with each other was maintained by talking as they went along. Even at a distance of a few feet it was impossible to see the beam of the other's spotlight through the snow. Suddenly one man stopped talking; and the other, in trying to locate his companion, fell about 20 feet, landing in a snow bank. While he was scrambling to get clear, his hand touched the ski of his companion, who had fallen head first. Both had walked off the edge



● AT LEFT: Extremely high winds make a 60 kv tower bow before the storm.

of the snow sheds over the Southern Pacific Railroad tracks.

Up to five o'clock in the morning no word had been received from these two men, who should normally have arrived by 4:00 a. m. The line crew was called from Rainbow Tavern and sent to search for them. About 6:45 a. m. the two men were found just as they arrived on the hill above the maintenance camp. Both men were completely exhausted, and one suffered the loss of one finger and the ends of two others, as well as frozen feet.

● Routine work during adverse conditions

Many laborious, routine duties are involved in maintaining continuity of service in times of extremely cold weather. To deliver the water for generation at the power houses, for domestic use, and for sanitation and fire protection, men work in relays during sub-zero weather chopping anchor ice in the canals, sometimes opening a half mile of canal in the daytime only to have it freeze again in spite of their continued work during the night. Debris and ice must be cleaned from the grizzlies at the head of the penstocks to permit uninterrupted flow through the turbines. Ball joint gaskets must be replaced in water-wheel pits, even though the spray forms ice as soon as it strikes the workmen's clothing.

Transmission and distribution lines loaded with snow and ice must be repaired during extremely low temperatures; and often it is necessary to use tractors and plod through the heavy snow on snowshoes or skis to transport material or drag poles into isolated regions.

During a storm, foremen and oilers intensely active in the hot boiler rooms at the standby steam plants; linemen endeavoring to maintain communication systems; messengers detouring many miles to carry word back and forth in case all communication is interrupted; operators sandbagging the doors and barricading windows of the power houses when rivers and creeks go on a rampage — all present an interesting picture changing with kaleidoscopic rapidity.

LOW INITIAL CURRENT STARTERS FOR SYNCHRONOUS AND INDUCTION MOTORS

● T. B. Montgomery
SWITCHGEAR DIVISION . . . ALLIS-CHALMERS MANUFACTURING CO.

● In specifying limitations in starting equipment for synchronous and induction motors, distinction should always be made between transient and steady-state starting conditions.

The transient condition incident to connecting the motor to the voltage source lasts from one to several cycles and usually produces no objectionable light flicker. Steady-state starting current is the sustained value of current drawn from the line as soon as the motor is energized and with the rotor at a standstill. Instead of being expressed in amperes, the proportional value of kva input is generally used and is called "starting kva."* The kva drawn from the line is, of course, determined by the standstill impedance of the machine. The amount of this starting kva determines the magnitude of the resulting disturbance on a given distribution system. However, the term "starting inrush" is often used. Strictly speaking, this term does not apply to steady-state conditions and should not be used in this connection.

The magnitude of disturbance incident to starting is also dependent on the ratio between the motor size and system capacity, or, more specifically, the capacity of the feeder supplying the motor. If this ratio is large, the use of starting methods generally considered standard would result in objectionable disturbances on the system or undue strain on the motor and equipment driven by it. The purpose of this article is to describe a method whereby motors may be started under such conditions without the usual undesirable effects.

● Large motors and large systems

With the increase in size and interconnection of power systems, the effect of disturbances occasioned by the starting of large motors becomes less and less. This fact is emphasized by the very large motors which have been applied for starting on large systems within the past few years. Often such motors are started across-the-line without noticeable effects on the system to which they are connected.

However, voltage fluctuations due to motor starting may be very noticeable on moderate and small systems when relatively large motors and lighting loads are connected to the same or closely associated feeders. To prevent such conditions from causing undue disturbances to other connected apparatus and affecting the stability of the system, additional reserve generating capacity in many cases must be kept in service.

Future standards of service, no doubt, will be as rigid, or more so, as those of today. Existing lines, however, probably may be used if motors and control equipment are sufficiently co-ordinated in design that the desired work may be done with reasonable starting currents. Even if existing lines cannot be used, the use of proper starting equipment will hold the additional investment required to a minimum. If proper starting equipment is procured, more favorable power contracts may usually be obtained.

There are of course applications where conditions are such that, even with proper starting equipment, low starting currents cannot be obtained. For example, with synchronous motor driven pumps, low speed and consequently correspondingly low starting currents cannot be obtained because of the speed requirements of the pumps.

● Reactance method simple and cheap

Of the two methods which have been most generally used for starting a-c motors, the reactance starting method has the advantage of being simpler and cheaper than other methods. Further, it does not require disconnection of the motor from the line during the starting cycle. Only one switch is required in addition to the line switch to handle the power circuit and the motor. Another advantage is that the reactor may be placed in the motor neutral, thus requiring only a two-pole switch for short-circuiting it. Moreover, the insulation requirements of the reactor and short-circuiting switches are not as great as if the reactor were placed ahead of the motor, but additional cost is added to the motor owing to the necessity of bringing out six leads. This arrangement is not adapted to delta-connected machines. In addition, without considerable complication, no more than one-step starting can be used. However, a big disadvantage of reactor starting is the relatively large kva consumed in the reactors which is proportional to the difference between the line voltage and motor terminal voltage at any instant during starting. Hence this method cannot be considered where minimum kva from the line is required.

Auto-transformer starting overcomes the objection of wasted kva from the line since the kva taken

* A. S. A. Standards for Rotating Machinery, 1936, Paragraph 3.150.

by the motor is approximately proportional to the square of the applied voltage and in addition any desired number of starting steps may be conveniently used. It is necessary, however, when changing from one starting voltage to the next higher one, to open the circuit. Consequently, when the next higher voltage is applied to the motor, the magnetizing current of the motor is added to the increased current to accelerate the motor which is applied suddenly, and this disturbance is imposed on the system.

The ideal starter would impress only sufficient voltage on the motor to supply enough current and, therefore, torque to start acceleration, and then gradually increase the torque to full-load value without disconnecting the motor from the line and without reducing the torque at any time during the starting cycle. Various methods of starting have been used to provide smooth starting with a minimum of kva required from the line, but in the systems used for the larger motors either special construction is required in the motor, as with part winding starting, or the torque is reduced during acceleration when changing starting voltages, as in the method where a portion of the auto-transformer is left in series with the motor to act as a reactor during the transition.*

• The auto-reactor starter

Figure 1 shows schematically, or line-to-line, the connections of an auto-reactor starter designed for starting synchronous and induction motors smoothly and with a minimum kva demand from the power system during starting. In this starter, after connecting the motor to the first starting step, the torque applied to the motor is increased in gradual increments during the starting cycle, and the motor is not at any time disconnected from the line nor is the torque reduced during transition from one starting voltage to the next.

The method combines the advantages of the reactance method of starting and the auto-transformer method.

The starter shown provides for two steps of starting voltage below line voltage. One or more steps may be used but more than three steps are usually not required, since the cost and complication would ordinarily be more than justifiable.

The starter is provided with a three-legged auto-transformer and three small reactors mounted in the same frame or tank.

In starting, the motor switch No. 1 (contactor or circuit breaker) is closed first to magnetize the auto-transformer. The closing of switch No. 2 applies the lowest starting voltage to the motor terminals, causing the motor to start. As soon as the motor has accelerated its load as far as possible on this voltage, switch No. 3 is closed. This switch, when closed, applies the next higher starting voltage and trips switch No. 2 automatically. It will be noted that during the short interval (approximately seven to nine cycles on a 60-cycle system), during which time both switches are closed, the short-circuit or circulating current through the switches produced by the short-circuited portion of the auto-transformer is limited to a nominal value by a small reactor in each leg. As the motor accelerates on the second step and the current decreases, the drop through this reactor decreases, thus gradually raising the voltage across the motor terminals. Switch No. 4 is closed to transfer the motor to full line voltage and the closing of this switch trips switches No. 3 and No. 1, thus disconnecting the auto-transformer. As on the previous transition, the circulating short-circuit current is limited by the reactors.

* (Korndorfer System.)

AT LEFT: Checking a wound rotor induction motor — 3500 hp, 257 rpm—on the test floor. This motor will drive a roughing stand of an 80 inch hot strip roughing mill in a large eastern steel plant.

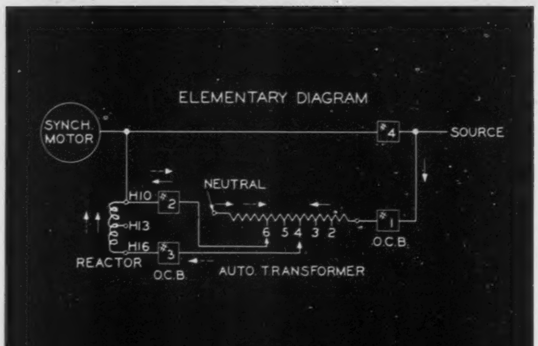


Fig. 1

• Synchronous motor starters

On synchronous motor starters, the field is usually energized and the motor synchronized on the second starting step before transfer to line voltage. However, since it has now become standard practice to have the field applied automatically even on manually operated starters (semi-automatic), the field switch may close at any point as soon as 95 per cent speed is reached.

The duty requirement of the starting switches on this starter is low and therefore maintenance is low. By referring to the elementary diagram, Fig. 1, it will be seen that the arrows indicate the instantaneous direction of currents at the instant of transfer from step No. 1 to step No. 2, when switches No. 2 and No. 3 are both closed. Note that the circulating current through switch No. 2 and the reactor is opposed to the current to the motor. Therefore with proper proportioning of the reactor, a smaller current is interrupted than is the case with a standard starter.

This method has been used on automatic starters up to 1750 hp; however, it is equally well adapted to manual or semi-automatic starters.

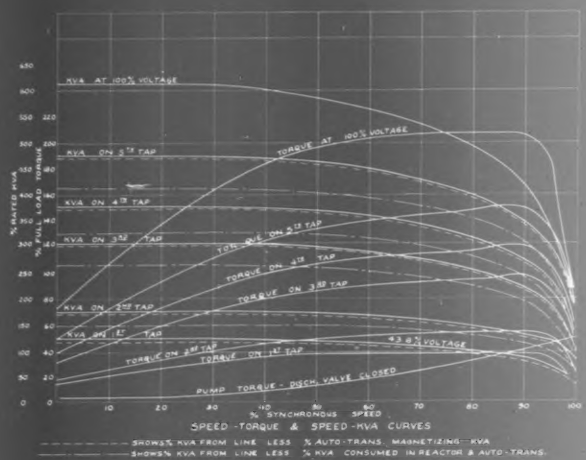


Fig. 2

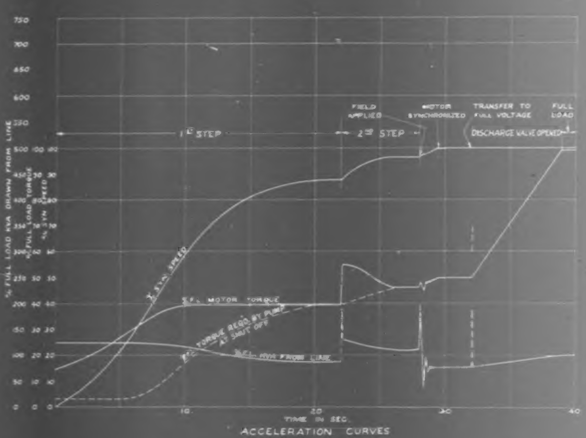


Fig. 3

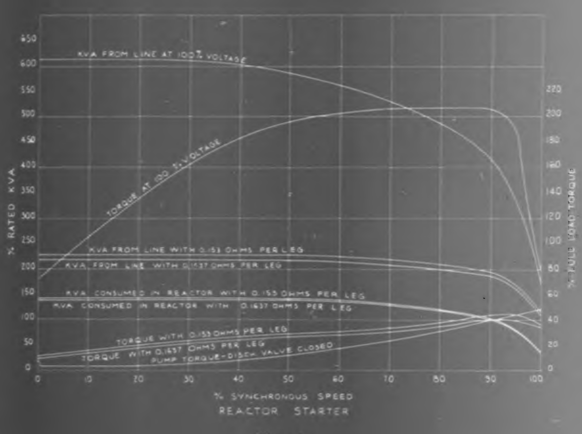


Fig. 4

Figure 2 shows the speed-torque speed-kva curves of a 350 hp, 440 volt, 3 phase, 60 cycle, 80 per cent power factor, 1800 rpm synchronous motor with direct-connected exciter driving an 8″ by 6″ centrifugal pump delivering 1750 gpm against a 635 ft head and controlled by an auto-reactor starter. This motor when started on full voltage would draw 618 per cent kva from the line initially and develop approximately 137 per cent starting torque. The motor develops slightly more than 100 per cent pull-in torque and has 225 per cent pull-out torque.

The first step of starting voltage used is 43.8 per cent and, when first connected to the line, 125 per cent full load kva is drawn. The motor accelerates to 88.7 per cent speed on this step, at which point 83 per cent full load kva is drawn from the line. At this speed, the motor is transferred to the second step of starting voltage on which connection 128 per cent full load kva is drawn from the line initially and the motor accelerates to 97 per cent speed. At this point the field is applied, causing the motor to synchronize with the line. The motor is then transferred to full-line voltage.

• Only two taps used

Only the first two taps of the auto-transformer are used, whereas five taps are provided. Curves of torque and kva drawn from the line are shown in Fig. 3 for all five taps. It will be noted that the torque curves on each step have an upward loop or swing as the motor approaches maximum speed on the particular tap. This is due to the increase in the terminal voltage of the motor owing to the decrease in drop across the reactor on account of the decrease in the accelerating current of the motor, resulting in the motor accelerating more than it would on a constant voltage tap.

Figure 3 shows the acceleration curves for this motor when starting the above pump using the auto-reactor starter.

Figure 6 shows an oscillogram of the starting of a 1200 hp low-speed motor by an auto-reactor starter. The small "hump" in the stator current after the motor has "pulled in step" is caused by the circulating current in the reactor on transfer to full voltage.

Figure 4 shows speed-torque curves for the same motor using a reactance starter. With the reactance starter, a maximum of 0.1637 ohms per leg can be used and

still give sufficient torque to start the pump. With this reactance, 222 per cent full load kva is drawn from the line in starting, of which 140 per cent is consumed in the reactors. However, with this value of reactance, the motor will only accelerate to 91.5 per cent synchronous speed, which is too low for successful synchronizing when field is applied. With 0.153 ohms per leg, the motor accelerates to 95 per cent speed at which point it can be successfully synchronized. However, the kva drawn from the line, at the initiation of the starting sequence, is 230 per cent full load kva.

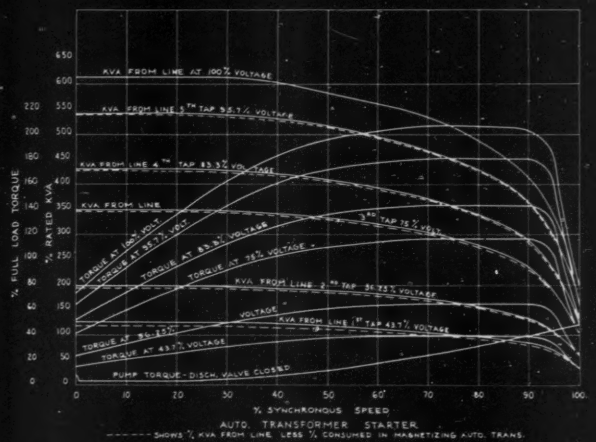


Fig. 5

Figure 5 shows the speed-torque curve with the auto-transformer only, as shown in Fig. 1. The kva drawn from the line is more on each tap, because of the fact that a higher voltage than shown in Fig. 2 is impressed on the motor, since with the auto-reactor starter the motor terminal voltage on each tap (except the first) is the auto-transformer tap voltage less the drop in the reactor. Also, the torque curves do not have the upward loop at approximately 90 per cent speed due to the decrease in current through the reactor. The inrush on changing taps is not taken into consideration on these curves.

• Additional cost justifiable

The auto-reactor starter uses the same number of starting switches as other starting methods. It is more applicable where two starting voltages, or taps, are required to produce sufficiently low inrush in starting a motor.

For a magnetic starter having two starting taps below full voltage, the cost of an auto-reactor starter in an average case is about 22 per cent more than the standard starter which disconnects the motor during transition from one voltage to the next.

It will be seen that while this type of starter is more complicated than the ordinary type, and is higher in cost, it may be utilized economically for many special requirements.

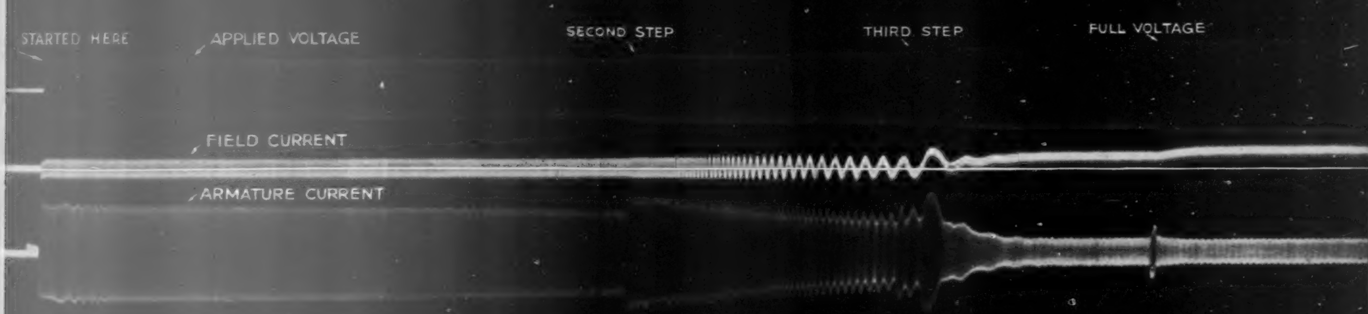


Fig. 6

PARALLEL OPERATION OF MERCURY ARC RECTIFIERS AND ROTATING MACHINERY

BY [illegible]
RECTIFIER DIVISION, ALLIS-CHALMERS MANUFACTURING CO.

● Many mercury arc rectifier applications involve the problem of parallel operation of rectifier units with each other or with other types of converting equipment, such as motor generator sets and rotary converters. Paralleling becomes an important factor where the load varies over a wide range, as in railway and mine haulage applications. It is generally of less importance in electrolytic plants due to their steady load conditions.

The problem of parallel operation depends upon the external voltage characteristic of all the converting units to be paralleled, and on the load division desired under varying load conditions for the given application. The problem is somewhat complicated where the supply frequency and voltage are subject to fluctuation, or where the units which have to operate in parallel are fed from different sources of power. For most cases, however, it is sufficient to assume constant supply voltage and frequency.

The fundamental difference in the parallel operation of rectifiers and converting equipments of the rotating type is the well-known property of a rectifier of conducting current under normal conditions in one direction only. When two motor generator sets operate in parallel, the set having the higher potential on open circuit will operate as a generator and supply power to the set of lower potential, and thus run it as a motor. A rectifier under normal operating conditions, on the other hand, can only transfer power from the a-c to the d-c side and is not capable of absorbing and returning it to the a-c supply. When operating in parallel with a motor-generator set, a rectifier will therefore participate in the power supply only when its voltage is higher than or equal to that of the rotating machinery, and as soon as its voltage becomes lower it will cease to operate, causing the motor-generator set to take over the entire supply of power. When operating in parallel with other converting equipment, this property of the rectifier has advantages and disadvantages, as will be shown later.

● Voltage characteristics of rectifiers

The inherent voltage characteristic of a mercury arc rectifier is of the shunt type, as there is a voltage reduction between no-load and full load, depending on the transformer connection employed, the copper losses and reactance of the rectifier transformer, the variation of the arc drop within the rectifier tank, and the characteristic of the a-c supply lines. The influence of the a-c supply on the d-c regulation of a rectifier is different than that of rotary type converters. Even with sustained a-c voltage the process of rectification results in a wave distortion of the a-c supply, which causes a drop in the d-c voltage. Assuming constant sinusoidal primary supply voltage and constant frequency, the d-c voltage regulation curve of a mercury arc rectifier unit with interphase transformer connection would be approximately as shown in Fig. 1.

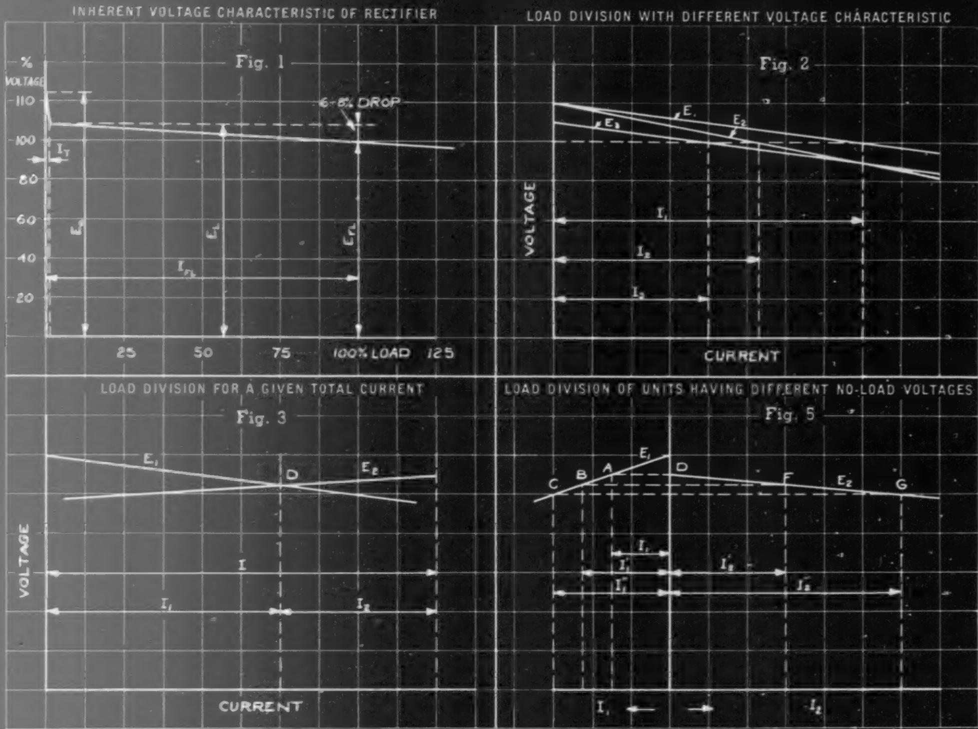
Low voltage rectifiers have a more drooping d-c voltage characteristic, for the reason that their arc-drop forms a greater percentage of the total voltage drop than is the case in a high-voltage unit. The d-c voltage regulation between light load and full load averages therefore eight to nine per cent for 250 volt rectifiers and six to seven per cent for 500 volt units.

The use of energized grids in the path of the rectifying arc of a rectifier provides a convenient means of modifying the d-c voltage with constant a-c supply voltage applied. However, the cost of the additional equipment necessary for grid control is considerable and usually makes this method attractive only for rectifier plants of large capacity and high d-c voltages. For small rectifiers, grid control is seldom competitive, as rotating machines can usually have their voltage characteristics modified without extra cost.

● Assumptions for parallel operation

For the purpose of investigating the parallel operation of plants, the sudden voltage rise of rectifier equipment with interphase connection at approximately one-half per cent load is usually neglected, and the curve giving the characteristic between light load and full load is extended to the zero ordinate. Unless special accuracy is desired, it is generally also satisfactory to assume the voltage characteristic to be a straight line instead of slightly curved.

The usual cases of parallel operation involve two or more rectifiers, or a rectifier and one or more motor-generator sets or rotary converters.



Ordinarily it is easier to obtain satisfactory parallel operation between two rectifiers, or between a rectifier and a rotary converter, than between a rectifier and a motor-generator set. The reason is, of course, that with both the rectifier and rotary converter the d-c voltage varies approximately proportionately to the a-c supply voltage, whereas the d-c voltage of the motor-generator set is directly affected by its speed, which in turn depends principally on the frequency, and, in the case of an induction motor driven motor-generator set, to a negligible extent also on the supply voltage. There are, however, many installations where synchronous motor-generator sets operate satisfactorily in parallel with rectifiers on variable load.

• Load division

Stable operation in paralleling two or more converting units is easiest to obtain when the units have drooping voltage characteristics. Fig. 2 indicates the division of load for various units having different voltage characteristics. For a given terminal voltage, the length of the horizontal line intersecting the voltage characteristic and the zero ordinate is a direct measure of the current supplied by each unit. From this diagram it can also be seen that equal load division from no-load to full load is possible only when the characteristics of the various units are straight lines which intersect at the same point on the ordinate axis. The slope of each voltage characteristic must be inversely proportional to the ampere rating of its machine. When the voltage characteristics are curves instead of straight lines, they must, in order to obtain equal load division, coincide at every point when plotted against per cent rated load. An equal drop of the d-c voltage, such as might be caused in rectifiers and rotary converters by an a-c supply voltage reduction, would not greatly disturb this load division, which accounts for the easier parallel operation of such equipments. With a motor-generator set the speed would scarcely change as long as the frequency remains constant and its d-c voltage would therefore not be affected. It would thus be called upon to take a larger share of the total load as can easily be determined from the diagram.

Where only two units are involved, the diagram, Fig. 3, can be so constructed as to give directly the load division for a given total load current. To this effect, it is only necessary to draw two ordinates at a distance of "I," corresponding to the total load current. The voltage characteristics drawn from opposite ends will then intersect at point "D," which shows the portion of load supplied by each unit.

• Adjusting for efficient operation

It is obvious from this diagram that when the characteristics are flat and approach a horizontal,

● Machining the water jacket of a 2500 kw mercury arc power rectifier.

as is the case with compounded units, parallel operation becomes unstable unless some special equalizing features are provided. With rectifiers this requires automatic grid control and compensated voltage regulators.

A rectifier installation of this type was recently put in service at a steel mill to supply general purpose power. This grid-controlled unit was designed with constant voltage control for cross-compounding and will be suitable for parallel operation with motor-generator sets or other rectifier equipment at some future date.

When operating a rectifier unit in parallel with a motor-generator set, it is frequently the practice to have the motor-generator set carry the base load, and leave the peak loads for the rectifier. This arrangement produces a favorable overall efficiency of the whole plant, as motor-generator sets are usually most efficient near full load, whereas the rectifier efficiency is more or less independent of the load, and higher economies are therefore attainable on light loads, the losses being quite small when idling.

In some cases it might be desirable to have the rectifier unit, instead of the rotating machines, carry the base load. A 1000 kv, 600 volt rectifier for this type of service was furnished some time ago. This unit was provided with automatic grid control for constant current supply and connected to a large 60-cycle system. The rotary converters with which this rectifier operates in parallel are fed from a 25-cycle supply and are allowed to take only the swings. This arrangement assures that the 60-cycle supply furnishes the major portion of the required power and the 25-cycle system is called upon to help along only on the peak loads. This installation is a good example of the versatility of grid-controlled rectifier equipment for various service conditions. Fig. 4 shows conventional efficiencies for 250 volt rectifiers and motor-generator sets of medium capacities. On higher d-c voltages the character of these curves remains the same, but the rectifier efficiency increases with the d-c voltage and soon exceeds the full load values of the motor-generator set.

Figure 5 shows how the load divides between a motor-generator set and a rectifier operating in parallel when the former is provided with a more drooping characteristic and the rectifier has a lower no-load voltage. The rectifier therefore starts to

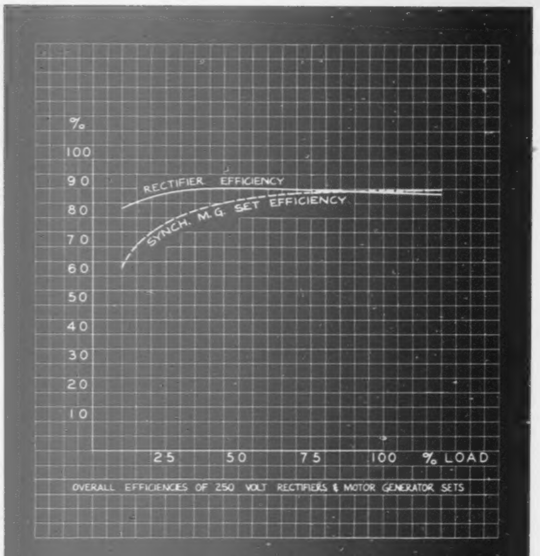


Fig. 4

supply current only at the load corresponding to the point "A" where the load current of the motor-generator set amounts to "I." However, owing to the flat characteristic, the rectifier will from there on take care of increasing proportions of the load, while the motor-generator set shares but gradually in the total load increase, as indicated by the various load points "B" and "C" in the diagram. All loads equal to or less than "I" will be handled by the motor-generator set alone, and the rectifier has the advantage of simply floating on the line. In doing so, it is consuming only such a-c power as is required to cover its own no-load losses which amount to one-third to one-half those of a rotating machine. An adjustment of the load division between the two types of machines is easily accomplished by either raising or lowering the d-c voltage of the motor-generator set by means of the field rheostat or by operating the rectifier from a different transformer tap.

When the motor-generator set or rotary converters are in adjacent substations some distance away from the rectifier unit, the voltage drop in the intervening d-c lines is usually sufficient to permit satisfactory operation of the rectifiers in parallel with flat-compounded machines. Where this is not the case, it is frequently permissible to shunt wholly or partly the series windings of the d-c machines to secure the necessary shunt characteristic for satisfactory parallel operation.

• Rectifiers do not regenerate

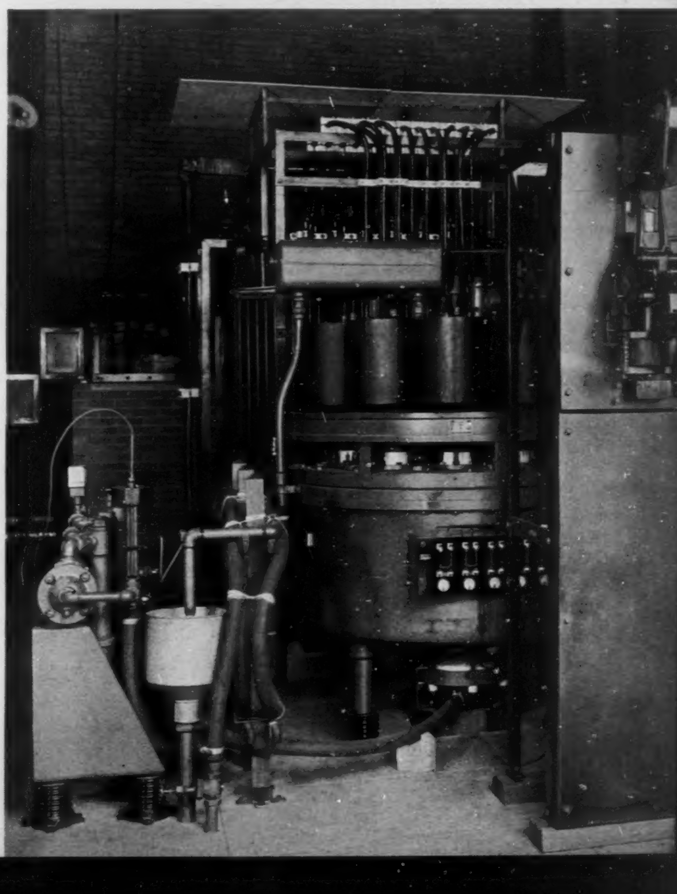
Because of their inherent characteristic of allowing current to flow in one direction only, mercury arc rectifiers cannot pass energy back to the supply system and consequently have the disadvantage of not being suitable for regeneration. When operating in parallel with motor-generator sets, or rotaries, any regeneration will therefore have to be accomplished by means of these rotating machines.

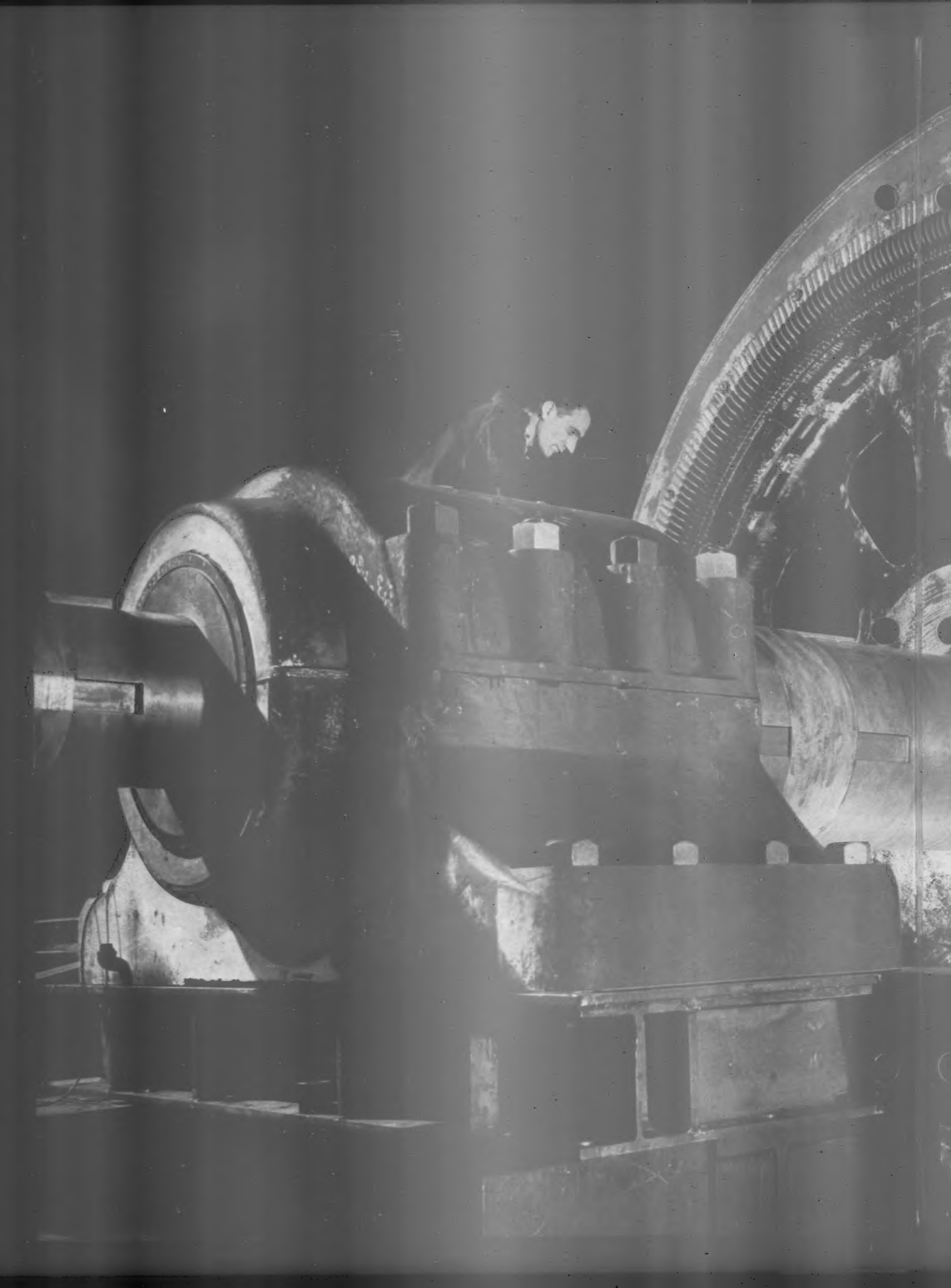
With the use of energized grids, rectifier equipment can be made suitable for inversion and can be used for regeneration. However, either a second tank has to be provided for this purpose or additional change-over equipment must be furnished. Although a number of such installations are in successful operation, so far the applications have restricted the use of rectifiers for regenerative braking to large units, high d-c voltages, and special applications.

From the above it is apparent that the problems of parallel operation lend themselves to simple graphical solutions, giving sufficiently accurate results for ordinary use. It must, of course, be realized that the voltage characteristics are usually not quite straight lines and that the influence of supply line reactances is considerably more pronounced with rectifier equipment than with converters of the rotating type.

● ON FOLLOWING PAGES: Assembled on the test floor, except for covers and flywheel, is the 3500 hp, 150 rpm wound rotor induction motor, rotor of which is shown on the cover. This motor will drive a broadside mill in an 80 inch hot strip roughing mill of a steel plant in the Pittsburgh area.

● BELOW: Automatic current control is effected in this 1000 kw, 600 volt mercury arc power rectifier by means of energized grids.





PRESENT-DAY LINE AND STATION INSULATION

● [illegible] Consulting Engineer

OHIO BRASS COMPANY · MANSFIELD, OHIO

● Today appreciably more is known about the electrical phenomena with which power line insulation must cope than was the case at the start of this century. Then lightning was believed to cause frequent insulation failures and system outages, but nothing was known of its nature. Within the past ten years, the proper instruments have been developed for investigating lightning in the field, and now its characteristics are rather well established. Simultaneously, generating and measuring equipments were created for duplicating and studying lightning effects in the laboratory. As a result, line insulation today may be designed to have the maximum possible resistance to lightning failure. This, coupled with the known advantages of proper ground wires and counterpoises, enables utility engineers to design lines which are practically "outage-proof."

The increased use of radio communication has provided the present-day transmission engineer with a new problem, with which his predecessor was probably never troubled, namely, radio interference from insulation and associated conductor supports. The methods of measuring, studying, and designing to avoid this interference will be touched upon later.

● Porcelain as insulation

Porcelain was one of the earliest insulating materials employed for transmission lines, and today it is by far the most frequently used form of outdoor insulation. Its outstanding characteristic for this service is its ability to withstand weathering without measurable electrical, chemical, or physical change. There are better insulating materials available in so far as puncture and mechanical strengths are concerned. Examples are the phenolic-treated fabrics. However, they lack the ability to maintain these properties under outside service conditions.

While porcelain will weather well, it is comparatively fragile and must be handled carefully. Too large masses must be avoided. Thick and thin sections in the same part must also be avoided, as differential stresses and resultant fractures may occur during severe temperature changes. Adjoining sections must have relief surfaces, such as treated sanded surfaces, to prevent differential stresses of thermal or mechanical origin from being transmitted. When metal hardware parts are added, great care is needed in shaping and assembling all parts to insure proper relief, as metal has twice the temperature coefficient of porcelain.

The form of line insulator first used and the one still found in greatest numbers on power lines is the so-called "pintype." Fig. 1 shows a cross sectional view of a typical modern pintype insulator. The electrostatic flux lines from line to ground and the corresponding equipotential lines are included to show the manner in which the porcelain surfaces have been made to conform to them. This conformation requires all surfaces to be parallel or perpendicular to flux lines and equipotential surfaces and thus causes minimum disturbances to the electric field established by the conducting parts. Stress concentration and local air breakdowns are thereby reduced.

● Balanced design

Electrical considerations cannot be the sole factor in design layout, since the insulator must also serve as a mechanical support for the conductor. Accordingly, the final result must be a compromise between electrical and mechanical considerations, and one that will function under any service or weather condition that might be encountered. The phrase often used, and which might be applied to almost any device, is "the design must be balanced."

In Fig. 2 are shown five possible design variations, each intended to accomplish a specific purpose but simultaneously creating an associated hazard. Design 1 of Fig. 2 has conical joints and thin shells which allow ready adjustment to all temperature changes and thereby afford thermal safety. However, it is apparent that the unit has little cantilever and uplift strength, has poor voltage distribution, and is very liable to flange breakage from blows and arcs. In Design 2, the outside surfaces conform well to the electrostatic flux lines and equipotential surfaces, and good voltage distribution is secured under normal conditions. However, because the surface resistance has been lowered and the porcelain parts vary greatly in thickness, the thermal hazard is increased. Design 3 affords high surface resistance but is difficult to manufacture, hard to clean, liable to break, and subject to localized over-stress of the air. Although Design 4 is rugged, it has the thermal hazard of heavy sectons and low surface resistance. Design 5, with its excessive overlapping of the pin, will handle cantilever loads especially well, but the large diameter and straight walls are thermally dangerous; and a long pin is required to provide adequate clearance to the crossarm below.

The so-called "standard type," in the center, incorporates each of the necessary properties to a

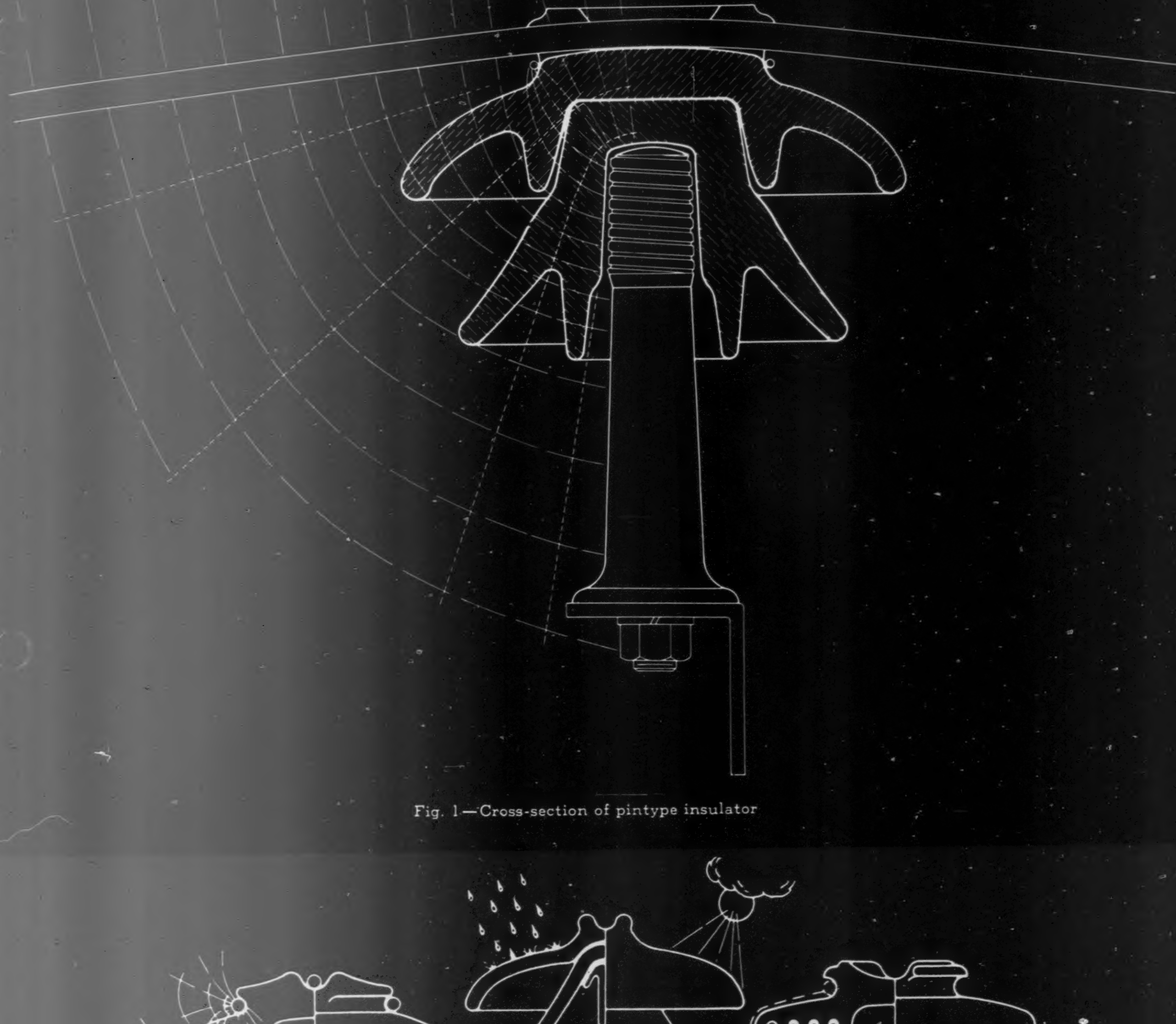


Fig. 1—Cross-section of pintype insulator

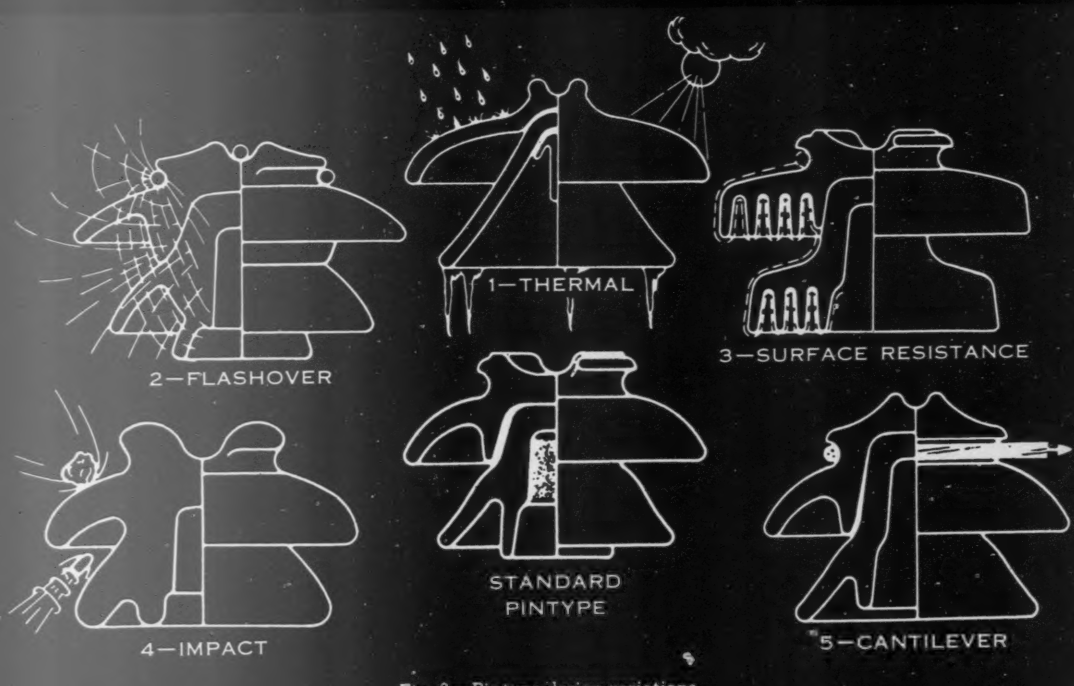


Fig. 2—Pintype design variations

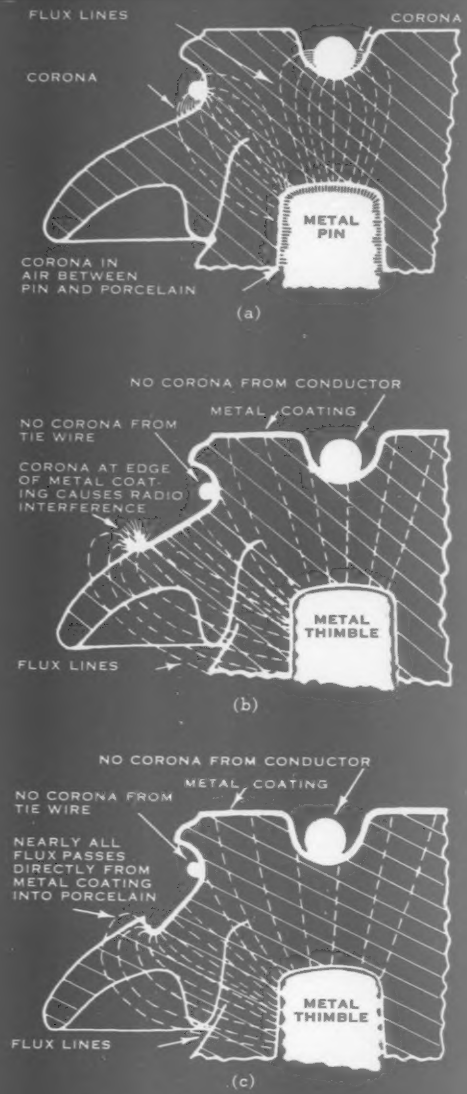


Fig. 3—Controlling insulator corona

Fig. 4—Radio proof insulator

sufficient extent to give the highest over-all electrical and mechanical efficiency. The merits of this balanced design are proved by the fact that its phenomenal service record, since it was first brought out over 25 years ago, has made it the most popular form now used in this country.

• Corona

Within recent years, the popularity of radio has emphasized the need of having insulators in some localities free from all localized discharges which might cause interfering radiation. Under sufficiently high operating voltage, the "standard type," referred to above, will experience local corona beneath the conductor and tie wire on the head and between pin and inside shell. While these discharges have never proved harmful to insulators or their operation in the past, their presence is undesirable now where radio reception is acute.

Figure 3a shows the location of the disturbing corona points. The condition creating these is merely that of series dielectrics of different permittivities or dielectric constants. In this case several shells of porcelain, having a dielectric constant of six, are in series with air having a dielectric constant of one. Since the voltage distributes inversely as the dielectric constants, it is obvious that the air spaces must assume considerably more voltage, relatively, than the porcelain bodies in series with them. Accordingly, this causes the air spaces to break down in the form of corona when the conductor voltage is increased sufficiently.

One method of eliminating corona in the air spaces is to short-circuit the air spaces so that there is no voltage across them. In Fig. 3b this is accomplished by applying a metal coating to the head of the insulator and cementing a metal thimble in the pin hole. However, this simple operation may not suffice entirely, because corona may appear at the edge of the metal coating as the electrostatic field in air now terminates at that point. This condition is shown in Fig. 3b.

One method of controlling corona at the edge of the metal coating is to under-cut the porcelain at the edge of the metal surface so that the flux terminating at this metallic edge passes entirely through porcelain (see Fig. 3c). It is obvious now that the intense part of the electrostatic field is carried entirely through porcelain, so that no air is there to fail and cause corona and resultant radio interference. Fig. 4 shows an exterior view of such an insulator.

Another method used by one manufacturer for taking care of the above corona problem is to coat the top of the insulator with a special glaze. This glaze, when fired, creates a surface which under a special liquid treatment develops metallic particles. These metallic particles are then tinned over to a point beyond the tie wire area. Corona from the edge of the tin surface is minimized by a graduated surface resistance extending outwards from that point. Other insulator manufacturers have taken care of radio interference on pintype units by cementing metal caps upon the heads — all of which tend to eliminate energized air spaces about the conductor and tie wire.

• Switch and bus insulators

As a rule, the switch or bus type of insulator, developed for supporting conductors and switch mechanisms in power stations, is merely the pintype with a metal cap and pin attached by cement. Accordingly, the same general design principles as illustrated in Fig. 2 are involved, and the same hazards must be avoided.

The presence of the attached pin and cap introduces the need for greater care in providing for the differential expansion and contraction of the metal on the porcelain bodies. The use of minimum metal wall thicknesses, avoidance of unnecessary overlapping of cap and pin, and the use of treated sanded surfaces will go far towards reducing this thermal hazard.

In cases where high cantilever strengths indicate heavy metal parts and appreciable overlapping, special refinements must be made to allow for the greater strains incurred when these parts contract and expand on the porcelain. For example, on all of the 10 ft switch insulator stacks of the new 287 kv Boulder Dam lines, such refinements were employed on the pins at the bottom units, as illustrated in Fig. 5. In this case the pin steps were so designed that all bearing surfaces lay in planes meeting at the same apex, while all other surfaces were arranged with adjacent air spaces to allow movement without contact with the cement. In this way the bearing surfaces transmit all applied mechanical loads directly to the adjacent cement surfaces, and radial expansion and contraction forces from the metal parts are taken care of by slippage along these surfaces.

• Suspension insulators

With the gradual increase in transmission voltages, it was necessary that the conductors be supported at continually greater distances from ground. One method of doing this was to increase the sizes of the pintype insulators. An obvious limit in this direction was reached when the units became large and bulky and, therefore, inefficient from the electrical and thermal standpoints. The suspension insulator then found favor because it allowed small units to be coupled in strings below the tower or pole arm supporting the conductors. The first units were of the inter-linked, or Hewlett, design. The "cap and pin" design (Fig. 6) soon appeared, however, and today it is by far the most popular. Obviously, the mechanical principles of the suspension unit must differ somewhat from the pintype. The conductor load on the assembly is tensional, and the units require intimately assembled metal fittings. As is the case with switch insulators, metal introduces new stress problems in the dielectric and requires additional precautionary features to take care of possible differential temperature stresses.

The same electrostatic principles apply to the individual suspension unit as to the pintype, so that surfaces must be shaped as previously noted. However, when hung in strings, the electrostatic field of the assembly is the primary factor, as it is only the failure of the complete string which causes a short-circuit to ground. The voltage to cause this failure is governed largely by the distribution of voltage stress among the various units in series.

All of the units of a string are of equal internal capacities, but they also have external capacities to ground, because of their hardware parts, as shown in Fig. 7a. In supplying charging currents from the line end to all of these condensers, it is obvious from Fig. 7a that the bottom insulators must carry more current than the ones above. In other words, the line unit carries all of the charging current to ground, the next unit less, etc. The unequal voltage distribution which this creates over the string is apparent from the curve of Fig. 7b.

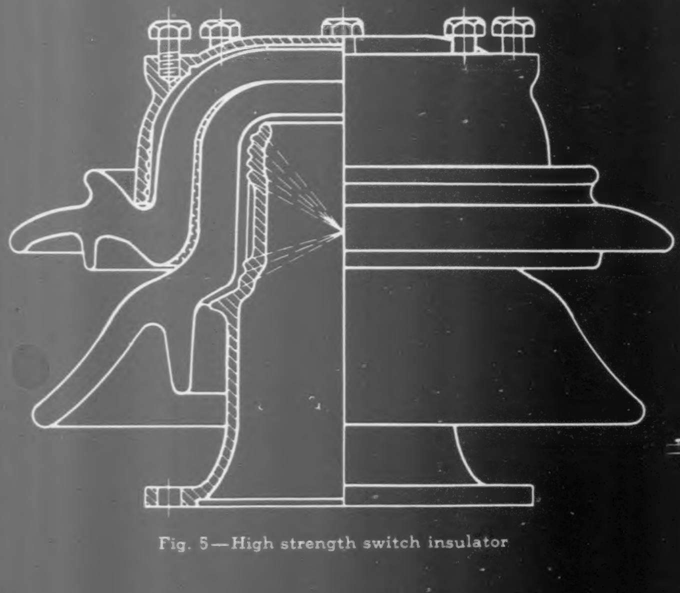


Fig. 5—High strength switch insulator

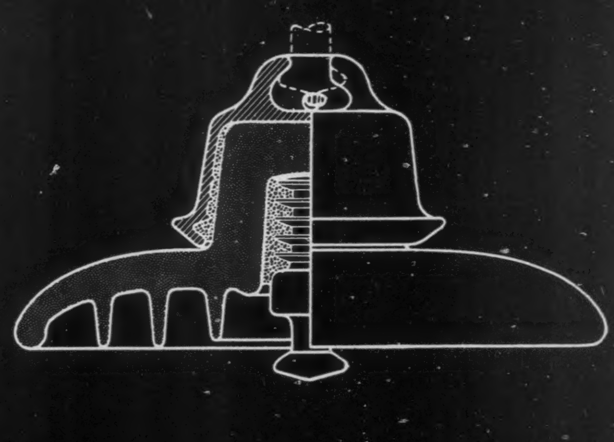


Fig. 6—Modern cap and pin insulator

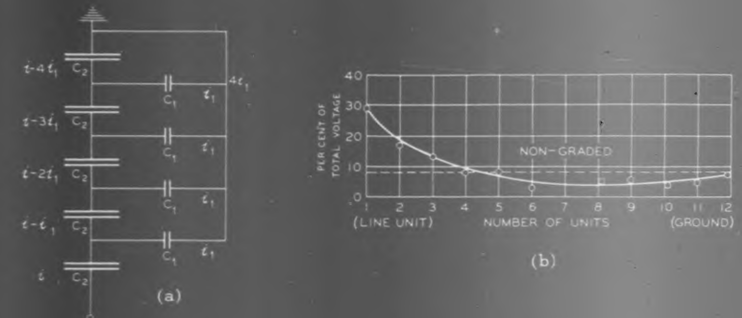


Fig. 7—Voltage distribution of unshielded suspension string (Peek)

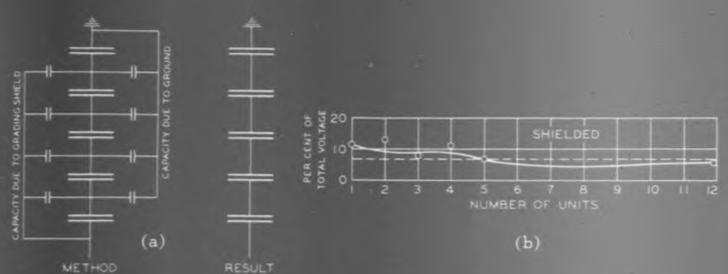


Fig. 8—Voltage distribution of shielded suspension string (Peek)

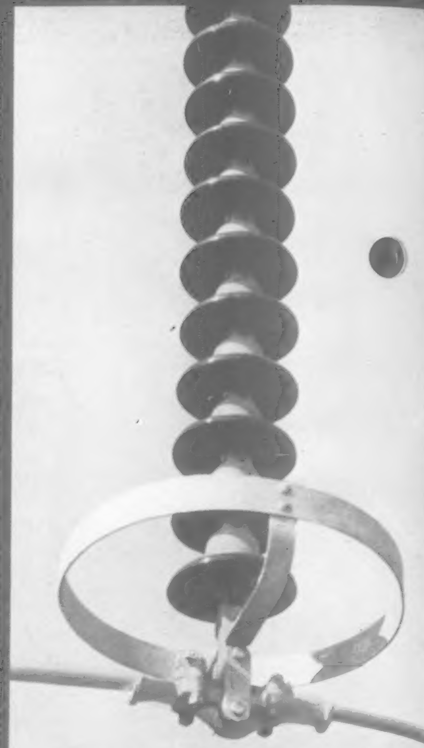


Fig. 9—Suspension string and shield

Fig. 1
of 2

• Insulator shields

If a shield, similar to that shown in Fig. 9, is added to the line end, it will furnish parallel capacitances to the insulator string hardware to compensate for the capacitances of the hardware to ground. This avoids the necessity of the bottom insulators carrying the charging currents of the other insulators. Fig. 8a shows this diagrammatically. The more or less uniform voltage distribution created is shown in Fig. 8b.

Since the above shield relieved the lower units of the excess potential that was measured without the shield, it was felt that the 60-cycle flashover voltage of the string would thereby be raised. Subsequent tests showed that the reverse was true and that the string flashover voltage was decreased 15 to 20 per cent by adding a shield. An analysis of the situation gave the following reason: The above potential distribution was measured at the operating voltage of the string, when little or no corona was present on the insulators. As the voltage on the unshielded string was raised to flashover, corona first appeared on the most highly stressed units. These discharges from the hardware increased the effective capacities of these units and automatically prevented any great excess voltages across them. By the time flashover was reached, the voltage distribution was approximately uniform, so that a shield would accomplish nothing — in fact, it reduced the flashover distance of the line end to ground and hence reduced the 60-cycle flashover voltage of the string.

With the introduction of laboratory impulse generating and measuring equipment, it was found that insulator shields really played some part in increasing the impulse flashover voltages of such strings. The circumstances, however, were different in that there was insufficient time before flashover for corona to form on the units and equalize voltages. In this way some slight increase in flashover voltage was shown by adding a shield to a suspension string. However, these conditions only held for very brief times of voltage applications, that is, when flashover occurred in less than a few microseconds. In Fig. 11 is shown comparative volt-time curves of a shielded string and an unshielded string. In this illustration it will be noted that the flashover voltage of the shielded string was appreciably lower than that of the unshielded string, except when flashovers occurred in less than about 4 microseconds. For times shorter than this, there is a slight increase shown for the shielded string.

In view of the above conditions, shields are no longer used on suspension strings with the expectancy of having higher flashover voltages. Their primary purpose at present is to protect the insulators and conductors from power arc damage. In Fig. 10 is shown a flashover study being made of the latest form of insulator shield, the primary purpose of this shield being to insure no arc damage to the conductor.

• Bushings

When the transmission voltage is brought into the station and then by means of insulating bushings into transformers and circuit breakers, extreme design care is needed in the design of these bushings due to the limited clearances in the cover holes. The electrostatic field that would be involved were air the only insulating medium would be that of a rod and a ring (Fig. 12).

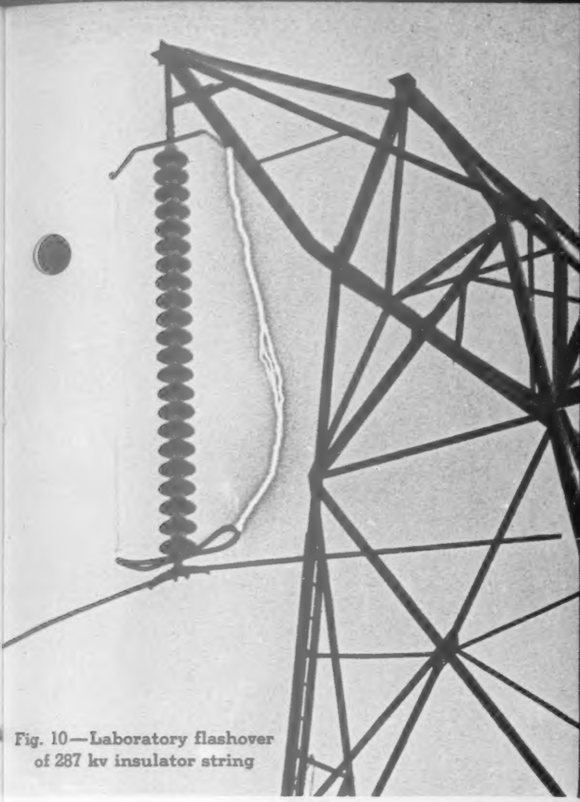


Fig. 10—Laboratory flashover of 287 kv insulator string

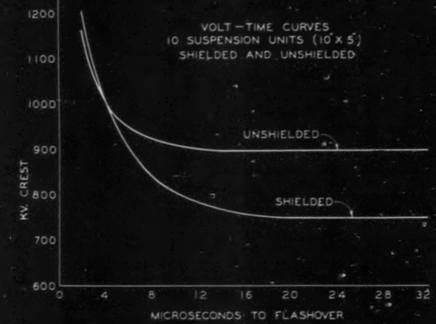


Fig. 11—Impulse voltage characteristics of shielded and unshielded strings

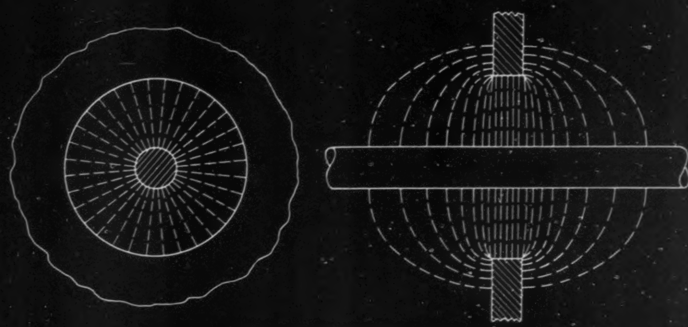


Fig. 12—Electrostatic field of rod and ring

It is obvious that the greatest intensity of flux—and therefore the highest voltage gradient—is at the rod surface in the plane of the ring. The stress can be relieved by arranging concentric metal cylinders about the rod with lengths inversely proportional to their radii (Fig. 13). A series of condensers of equal capacities is thereby created between the conductor and ground so that, with no stray flux, the voltage is divided equally among them This is roughly the principle used in the so-called "condenser type" bushing. However, in actual practice, stray flux to ground is present and passes through the innermost cylinders but not through the outer ones. In order to allow the innermost cylinders to carry this excess flux and still have the same voltage across them as the others, they must be made increasingly longer. It is obvious that this results in an extremely long bushing, particularly if the outside diameter is maintained large enough to allow sufficient insulation to ground for guarding against puncture. A uniform solid material is generally used to provide insulation between cylinders. The serious disadvantage to having concentric metal layers about the conductor is that any flaws in the intervening insulating cylinders will automatically be connected in series. Also, unless appreciable end insulation is provided, difficulties are often encountered in preventing discharges between edges of the adjacent metal cylinders.

• Grading inside insulation

Another method of reducing stress concentration around the conductor is to grade the inside insulation as is done in high voltage cables. In other words, a smooth, well-rounded, ground sleeve may be designed, and insulating cylinders of varying permittivities or dielectric constants arranged about the conductor with the innermost cylinders having the highest permittitivies. The effect is apparent from the simple cable example of Fig. 14. Assume three materials, all having a puncture strength of 100 kv per centimeter but dielectric constants of 5.5, 3.5, and 2.0, respectively. Let three cables be made, one with any of the three materials alone, and the other two with all three materials. In one of the latter cases the materials are arranged with that of the highest permittivity innermost, while in the other cases this order is reversed. In Fig. 14 the voltage stress diagrams are shown for each case, with the maximum potential so chosen as to cause no material to be stressed beyond its breakdown gradient, namely, 100 kv per centimeter. It is obvious that the areas of these gradient-versus-radius curves represent the total voltages sustained in each case. It will be noted that in Fig. 14b the greatest voltage is sustained.

In selecting insulating materials of various permittivities, the choice is rather limited as other requirements of puncture strength, durability, costs, etc., must be met. For this reason, the materials usually chosen in present-day bushings are porcelain, oil, varnished cambric, and phenol or shellac-treated paper and cloth cylinders. Oil is generally always used in the higher-voltage bushings because of its ability to carry away heat from over-stressed areas and its self-healing property following breakdown. However, it has a relatively low puncture strength and is seriously weakened by moisture and its own deterioration (sludging). The phenol and shellac-treated cylinders have particularly high puncture strengths, but are affected by moisture and will carbonize if subjected to any discharges. Varnished cambric has similar properties. Porcelain has fairly high puncture strength, although not

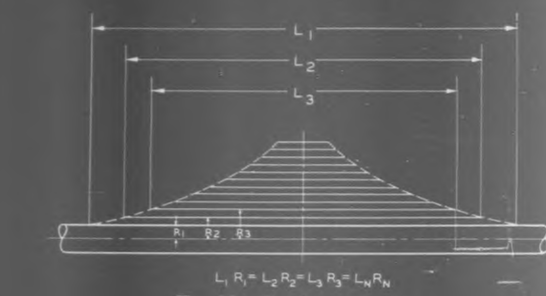


Fig. 13—Condenser bushing

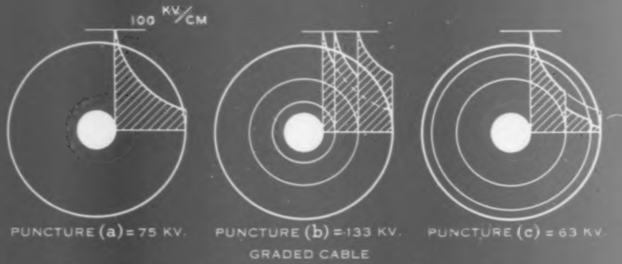


Fig. 14—Controlling voltage gradient of cable (Peek)

nearly that of treated paper and cloth cylinders. Its greatest asset is that it is unaffected by moisture or any other impurities. In addition, electrical discharges around it have no effect upon its properties.

Figure 16 shows a quarter sectional view of a 115 kv bushing in which the voltage gradient control is accomplished by using two different systems of dielectrics as in the cable above. With oil alone in all the zones between the porcelain cylinders, it will be noted that the innermost oil zone assumes over 28 per cent of the total voltage to ground, since the relatively high dielectric constant of porcelain (6) compared to the low constant of oil (2) forces the latter to assume relatively more voltage. By adding cambric to the innermost oil zone, its dielectric constant is raised to four, and the voltage across it decreases considerably. When cambric is added in this manner, all other zones assume more voltage, particularly the innermost porcelain cylinder. The latter, however, can better withstand the increased voltage stress because of its high puncture strength as compared with oil.

• Wood as line insulation

Wood in air withstands lightning voltages well but is practically worthless as insulation against 60-cycle voltage and will frequently be charred to destruction by it. Accordingly, ample and reliable porcelain insulation must be provided between the conductor phases to support their normal voltages. Wood may then be placed in the same series path but for the purpose of resisting only lightning voltages which might appear on the conductors. This behavior of wood can probably be explained by analyzing its method of conducting current. In other words, the current flow must be electrolytic since its path is through the moisture cells. If appreciable 60-cycle voltage is allowed across the wood, the current-carrying capacity of the cells is soon exceeded, and burning occurs. Lightning, however, exists only for a few microseconds, which is too brief for any current flow that depends on relatively slow electrolytic ions. Accordingly, no appreciable lightning charge is drained through the wood and no burning occurs; consequently, considerable lightning voltage (100 to 150 kv per foot) may be sustained.

The ultimate failure of wood from lightning voltages usually involves no charring, as it is merely split or splintered from the internal pressures set up. Fig. 17 shows such a failure in service where one plank of a double arm has been shattered. Fig. 18 shows an actual laboratory flashover of a similar structure made in connection with artificial lightning studies.

These studies to date seem to indicate that the lightning breakdown of wood is principally affected by the internal moisture present and not to a great extent by the form of creosoting or other internal impregnation. There seems to be little difference in the dielectric strength of the ordinary kinds of woods tested, provided similar moisture conditions are present.

• Porcelain and wood combinations

When porcelain insulation and wood are combined on a structure, the lightning flashover voltage of the combination is somewhat less than the sum of the individual flashover voltages measured separately. In the case of one wood and one porcelain member, tests indicated that the flashover voltage of the combination is about 90 per cent of the sum of the individual flashover voltages.* Where more than two individual members are used, the total measured voltage is about 75 per cent of the sum of the individual voltages.

It is felt that this reduction in flashover potential is largely due to the irregular distribution of voltage between the porcelain and wood insulation in series, as affected by their relative capacities. The resultant over-stressing of individual members would cause their early failure well before the others had been stressed to their breakdown points. The electrostatic fields of the various series members might also differ, resulting in different time lag characteristics, which tend to reduce the combined insulation strength. This apparent "reduction" of flashover voltage when wood and porcelain are put in series is illustrated in the volt-time curves of Fig. 15 where the "arithmetical total" is seen to be somewhat above the actual "measured total" of the porcelain-wood combination.

* "Lightning Strength of Wood in Power Transmission Structures"—Sporn and Lusignan, A. I. E. E. Transactions, 1938, p. 91.

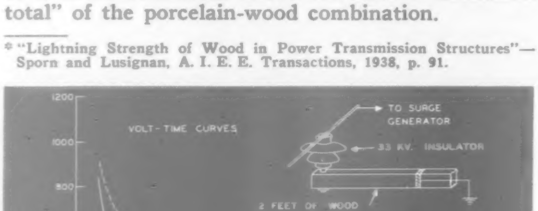


Fig. 15—Combined flashover characteristics of porcelain insulator and wood

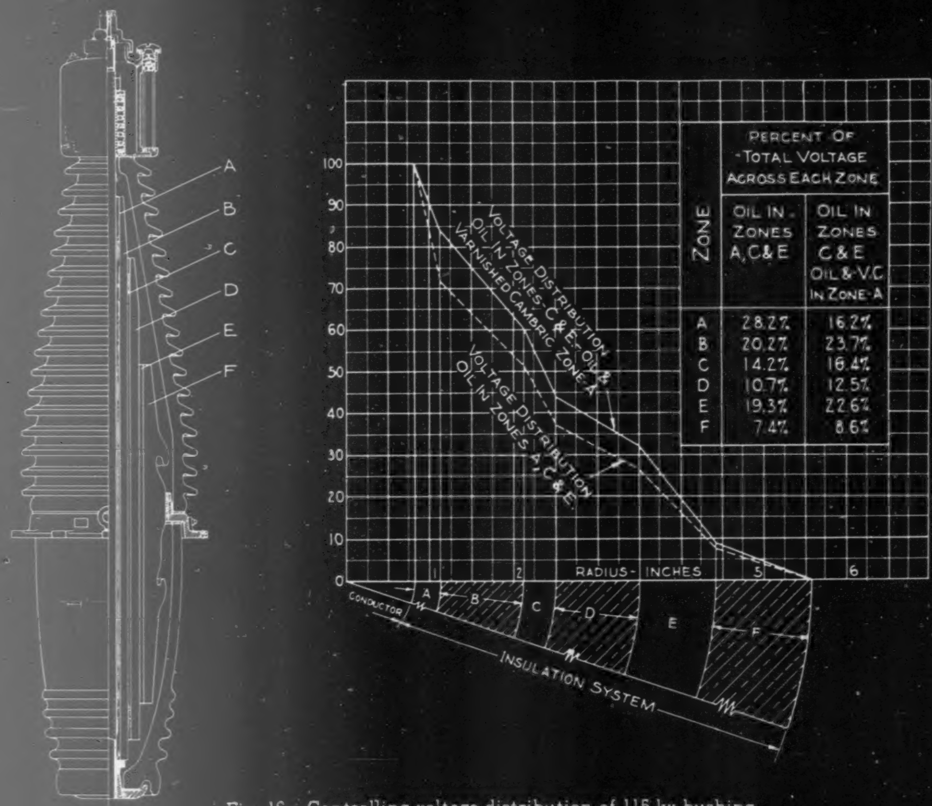


Fig. 16—Controlling voltage distribution of 115 kv bushing

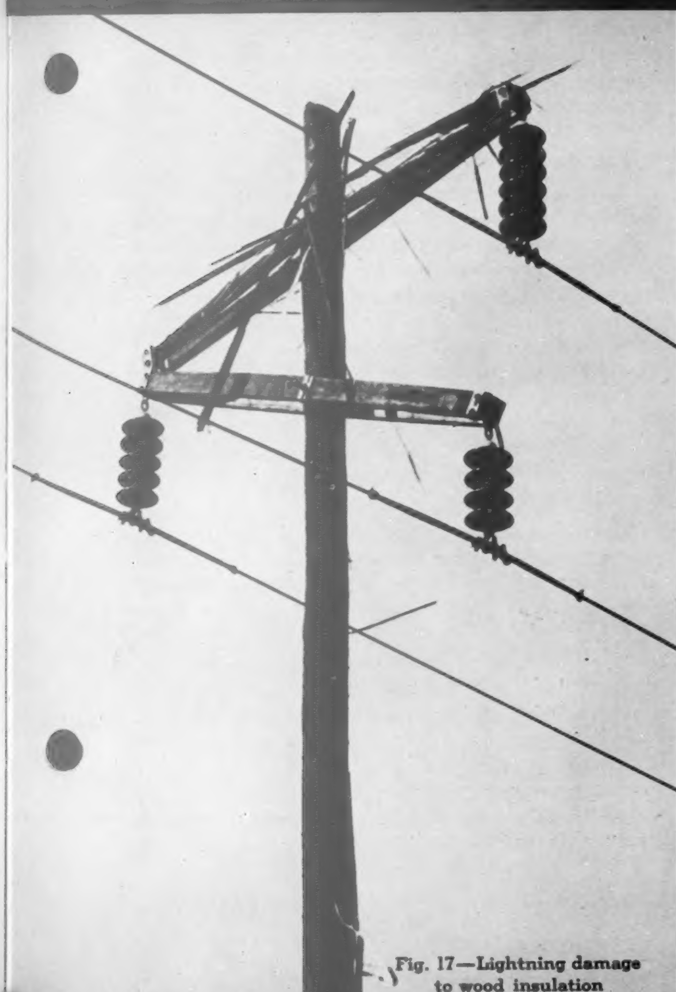


Fig. 17—Lightning damage to wood insulation

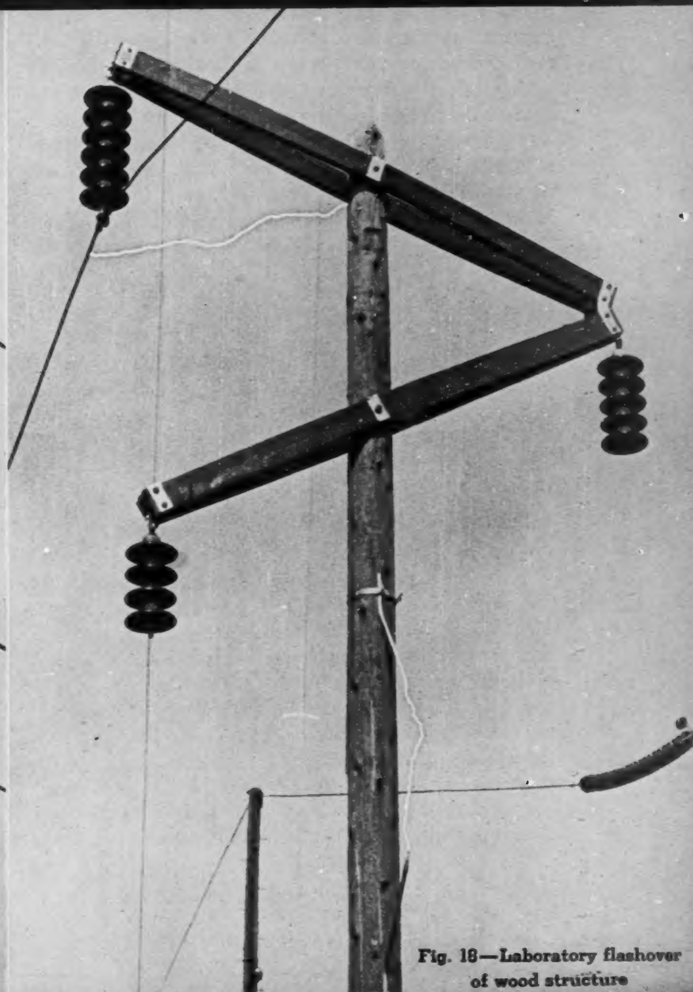


Fig. 18—Laboratory flashover of wood structure

ENGINEERING FUNDAMENTALS

FROM CATHODE TO ANODE IN A MERCURY ARC POWER RECTIFIER

● The action of the mercury arc rectifier depends on the fact that current can flow only in one direction between two electrodes in a vacuum, if one of the electrodes is a small pool of mercury and the other a piece of iron or carbon.

Since under certain conditions electrons can be readily emitted from mercury and not so readily from iron or carbon at low temperatures, the mercury pool will become the cathode, as the electron-emitting electrode is called; and the iron or carbon electrode will become the anode, or electron-receiving electrode.

● Other types of cathodes

Other structures besides a pool of mercury may be used as cathodes. One of the commonest, and certainly the most familiar, is the hot cathode used in the tubes of radio sets. In the early days of radio, the cathode of the tubes consisted merely of a tungsten filament, heated to incandescence by current passing through it. Later, the filamentary cathode was treated with thorium, an element which greatly increased the number of electrons that could be liberated at a given temperature. Still later, with the introduction of a-c operated radio sets, the cathode filaments were incased in ceramic insulating tubes, which became heated and, in turn, heated the actual electron-emitting metal cylinders.

Any of these different types of cathodes may be used for a rectifier tube, but the number of electrons which can be emitted by a heated cathode is limited to a much smaller value than the 5000 or more amperes which a cathode consisting of a mercury pool can readily discharge continuously. Such a current represents the flow of some 30,000,000,000,000,000,000,000 electrons for each second of operation.

● Self-restoration in a rectifier

Due to the relatively small number of electrons emitted from the cathodes in radio tubes, their life is comparatively long; and, in any case, the replacement of the whole tube is a minor expense. In the present stage of development, the life of hot cathodes used for emitting larger currents of the order of hundreds of amperes is somewhat shorter; and the replacement of these large power tubes represents a much greater financial outlay. Although the cathode mercury of a pool-type rectifier evaporates because of the intense heat generated, the vapor condenses in the cooler portions of the vacuum chamber, and the mercury flows back to the cathode in the bottom of the chamber under the influence of gravity. Thus the cathode is automatically and continuously being restored to its original condition.

For these two principal reasons — high current capacity and unlimited life — the mercury-pool type of cathode today is given almost universal preference for large power rectifiers.

The use of a pool of mercury as the cathode brings with it still another great advantage, namely, providing a convenient means of lowering the voltage drop as the current passes between the electrodes. This voltage drop is produced, as in a solid conductor, by the resistance which the current encounters in its path between the electrodes. In an electronic discharge device, the internal voltage drop rises as the vacuum is improved, until it reaches a very high value when the amount of residual gases becomes so small that no more can be evacuated by means of the vacuum pumps at present available. (Even under those conditions, however, many billions of gas molecules still remain in each cubic centimeter of space.)

● Voltage drop decreased

If, now, some gas or vapor is introduced into the space between the two electrodes, the electrical resistance of the path between them becomes less, or, to put it differently, the voltage drop is decreased. This decrease in the electrical resistance of the current path between the cathode and the anode can be effected by any one of a number of gases or vapors which may be introduced into the vacuum chamber; however, the fact that some of the mercury in the cathode pool is vaporized by the heat liberated at the cathode spot provides a convenient and automatic source of metallic vapor for this purpose.

The voltage drop in the arc, including the drop at the anode and that at the cathode of a rectifier of the mercury-pool type, is in this way reduced from a very high value — a good vacuum is an excellent insulator — to something like 15 to 25 volts, depending on the size and type of rectifier. The voltage drop remains almost constant, in a given rectifier, under all load conditions, the only exception being that during the first few moments of operation the arc drop may be somewhat greater; however, as soon as sufficient mercury vapor has been generated, the voltage drop resumes its normal value.

THERMAL EFFECTS ON SHORT CIRCUIT CURRENTS

SWITCHGEAR DIVISION . . . ALLIS-CHALMERS MANUFACTURING CO.

● Present-day requirements have resulted in the building of large power stations and the tying together of large numbers of high capacity units. These requirements have created new problems and required new methods of analyzing designs of equipment used on such systems.

The two main disturbances giving rise to abnormal stresses in electric systems are electromagnetic and electrostatic energy fluctuations. It is difficult to estimate the magnitude and fluctuations of these abnormal stresses, but with careful planning, and from the experience with large power systems having similar problems, it is possible to decide with reasonable accuracy the allowances to be made for abnormal conditions. The following formulas are useful in analyzing the thermal effect of short circuit currents in various kinds of apparatus.

Damage to electrical systems due to short circuit has generally been attributed to magnetic forces; however, consideration must be given to the fact that when a large amount of energy is suddenly applied, it may momentarily heat the conductor to such an extent that even a relatively small mechanical force may cause serious damage. This is evident from the following table of relative tensile strengths of copper and aluminum at various temperatures:

Table 1

Temperature	Tensile Strength Copper	Tensile Strength Aluminum
0° C.	100%	100%
200° C.	73%	57%
300° C.	53%	33%
400° C.	35%	14%
600° C.	14%	5%

The determination of the data on which designs are to be based divides itself naturally into two parts: first, a calculation of the magnetic forces involved; and second, a calculation of the temperatures reached during abnormal conditions. Since published data on computing mechanical stresses and magnitudes of short circuit current is generally available, this article will be confined to the second part of the problem and will deal particularly with the temperatures reached during transient conditions.

To calculate the heating during the transient period, the mean square value of the current during this period must first be computed, because the heating is proportional to the i^2rdt value. For current decreasing in accordance with a simple exponential function of a sine wave, the following equations of the transient current can be written.

$$I_t = (I_M - I_S)\, e^{-Bt} \qquad (1)$$

Where

I_t = rms value of transient currents at time t

I_M = rms value of maximum current at time 0

I_S = rms value of maximum current at time ∞ or the value of current after a transient period

B is a factor.

The stationary short circuit current as a function of the maximum current peak can be expressed as

$$I_S = f\, I_M$$

Where f is a factor.

By inserting this expression in equation (1) and adding the stationary current components, equation (2), shown in Fig. 1, is obtained.

$$I_{Mt} = I_M \left[(1-f)e^{-Bt} + f\right] \qquad (2)$$

Since the heating is directly proportional to the time and varies as the square of the current, it can be expressed as:

$$\int_{t=0}^{t=t} i^2 dt$$

Squaring equation (2) and integrating between the limits t=0 to t=∞ and subtracting the component of the stationary short circuit currents results in equation (3).

$$\int_{t=0}^{t=\infty} (I_{Mt}^2 - I_S^2)\, dt = I_M^2 \frac{(1-f)(1+3f)}{2B} = K I_M^2.$$

$$\text{Where } K = \frac{1+2f-3f^2}{2B} \qquad (3)$$

The value of (B) is the decaying factor corresponding to R/L and varies during the transient period, but an approximate value can be found by selecting a point on the curve of Fig. 2 spaced apart a distance equal to the time desired.

$$i_2 = i_1\, e^{-Bt}$$

$$\therefore\ Bt = 2.3 \log_{10} \frac{i_1}{i_2}$$

Table 2 is calculated from short circuit current factor curves of modern machines for the time t=1.00 second. (See N. E. M. A. Standards SG6-78).

Table 2

Factors for Three-Phase Short Circuit

Circuit Reactance	5%	10%	20%	30%	50%	100%
B	3.34	3.14	2.22	2.17	2.28	2.81
f	.058	.114	.230	.304	.415	.509
K	.166	.227	.294	.307	.288	.221

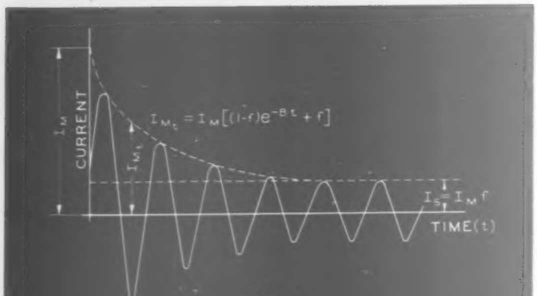


Fig. 1

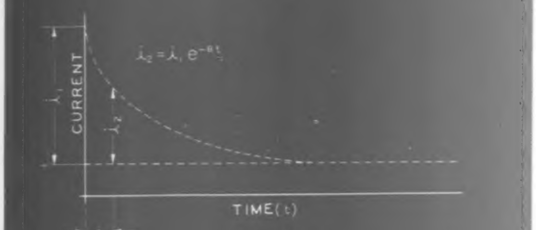


Fig. 2

The value of (K) as given by equation (3) is true only when the time (t) involved is sufficiently long to permit the short circuit current to reach its final value. For shorter time than this, (K) must be computed from the general equation for the limits t=0 to t=t which gives

$$K = \frac{1+2f-3f^2}{2B} - \frac{1-f}{B}\left[\frac{1-f}{2}e^{-2Bt} + 2\,fe^{-Bt}\right] \quad (4)$$

This value has been computed for ($K\infty$) equal to .25 in Fig. 3.

With the factor (K) determined, and consequently the value of $i^2t = \int_0^t i^2dt$, the heating due to this current can be calculated. If the increase in temperature for a short increment of time is expressed by (dv), the following equation can be written:

$$dv = \frac{i^2Rdt}{N\,G} \quad (5)$$

v and dv = temperature rise in centigrade degrees
i = current in amperes rms values
t and dt = time in seconds
G = weight of material in kilograms per decimeter cube
N = watt per kg per 1° C. rise = 427×9.814 ×specific heat of material
R = resistance in ohms
S = specific resistance = ohms per square millimeter and one meter length
1 = length in meters
S_1 = specific weight of material
a = area in square millimeters
A = area in square inches
a_1 = increase of resistance per degree centigrade

The resistance at the temperature (v)

$$Rv = R\,(1+a_1\,v) = \frac{S1\ (1+a_1\ v)}{a}$$

But $G = a\,1\,S_1 \times 10^{-3}$ Kg

Inserting this in equation (5) and separating the variables gives

$$\frac{dv}{1+a_1\,v} = \frac{S\times10^{-3}}{a^2S_1\,N}\quad i^2dt$$

Integrating both sides from v=0 to v=v and t=0 to t=t

$$v = \frac{\left(e^{\frac{S\,a_1\,10^{-3}}{a^2S_1\,N}\int_0^t i^2dt}\right) - 1}{a_1} \quad (6)$$

This is the fundamental equation from which the heating can be computed for any conductor whose constants are known, neglecting the cooling which is negligible in the short time involved. It is generally of interest to find the area required in order that the temperature rise shall not exceed a certain predetermined value. This is obtained by rearranging equation (6) and using common logarithms.

$$a = \sqrt{\frac{a_1\,S\,10^{-3}}{S_1\,N\,2.3\,\log_{10}(1+a_1\,v)}\int_0^t i^2dt} = C\sqrt{\int_0^t i^2dt}$$

The values of (C) for various materials and temperatures are given in Table 3.

In Table 3, (C) has been multiplied by 1000 to avoid small fractional numerals; hence, C′=1000 C.

Using the above values of (C′) results in the following simple formulas:

1. Heating due to excess currents only during transient period:

$$a = \frac{C'\,I_M\sqrt{K}}{1000}\ \text{sq. mm.}$$

$$A = \frac{1.55\,C'\,I_M\sqrt{K}}{1,000,000}\ \text{sq. in.}$$

2. Heating due to sustained short circuit currents only:

$$a = \frac{C'\,I_M\sqrt{f^2t}}{1000} = \frac{C'\,I_S\sqrt{t}}{1000}$$

$$A = \frac{1.55\,C'\,I_M\sqrt{f^2t}}{1,000,000} = \frac{1.55\,C'\,I_S\sqrt{t}}{1,000,000}$$

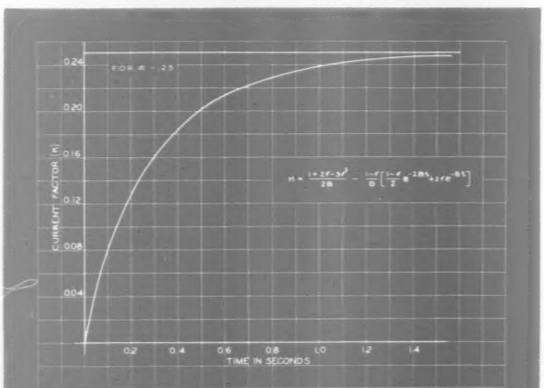


Fig. 3

Table 3													
Material	S_1	S	N	a_1	$C' = 1000°\ C = 1000\sqrt{\frac{a_1\, S\, 10^{-3}}{S_1\, N\, 2.3 \log_{10}(1+a_1 v)}}$								Fusing Temp. Centigrade
	Kg/dm³	mm²/M	Watts/Kg		Temperature Rise in Degrees Centigrade								
		15° C 68° F	1° C Rise	1° C Rise	50°	100°	200°	300°	400°	500°	750°	1000°	
Copper	8.9	0.0175	393.7	0.00445	10	7.78	5.92	5.13	4.66	4.36	3.9	3.62	1084
Aluminum	2.7	0.03	879.6	0.0037	16.65	12.2	9.21	7.92	7.19	6.7	5.94	5.51	657
Iron	7.8	0.143	481.7	0.0048	29.2	21.6	16.5	14.3	13.	12.2	10.95	10.2	1600
Lead	11.3	0.20	129.8	0.00387	54.8	40.2	30.4	26.2	23.8	22.1	19.7	18.3	327
Silver	10.5	0.0172	234.5	0.00377	12.3	9.08	6.85	5 91	5.3	5.0	4.43	4.12	962
Constantan	8.8	0.488	410.5	0.00005	51.8	36.6	25.8	21.1	18.1	16.3	13.5	11.5	1260

Table 4

COPPER WIRE

60 Cycles 20% Reactance $k=.24$ $f=.372$

Size of Wire	Maximum rms amperes for 1 sec and for temperature rises indicated					
B & S Gauge	DECREASING WAVE AMPLITUDE			CONSTANT WAVE AMPLITUDE		
	100° C	200° C	300° C	100° C	200° C	300° C
#2	7020	9220	10640	4330	5700	6570
#4	4420	5800	6710	2730	3590	4140
#6	2780	3650	4210	1725	2270	2620
#8	1750	2300	2650	1082	1412	1640
#10	1100	1445	1670	682	890	1034
#12	691	908	1048	427	556	647
#14	434	570	659	268	350	406
#16	274	360	416	169	223	256
#18	173	227	263	106	140	161
#20	107.7	141.3	163.1	67	88	101
#26	26.9	35.3	40.8	52	68	78
#30	16.6	21.8	25.2	33	43	50
#36	2.6	3.4	3.9	16	21	24

3. Heating due to both excess and sustained short circuit currents:

$$a = \frac{C'\, I_M \sqrt{K+f^2 t}}{1000} \text{ sq. mm.}$$

$$A = \frac{1.55\, C'\, I_M \sqrt{K+f^2 t}}{1{,}000{,}000} \text{ sq. in.}$$

Using the values of (K) and (C′) given, it is easy to compute the minimum area required in order not to exceed a certain predetermined temperature rise. The area given by the above equations of course presupposes an equal current distribution. The area must therefore be corrected for unequal current distributions, which roughly can be done by selecting an area whose alternating current resistance for the frequency used is equal to the direct current resistance of the area computed.

For a rough approximation of the conductor area required when the maximum short circuit current I_M is known, the following empirical equation can be used:

$$A = N\, I_M \sqrt{t}\, 10^4 \text{ sq. in.}$$

Table 5

COPPER STUDS

60 Cycles 20% Reactance k=.24 f=.372

Diam Inches	Actual Area Sq Inch	Corrected Area Sq Inch	Maximum rms amp for 1 sec and for temperature rises indicated: Decreasing Wave Amplitude 100° C	Decreasing Wave Amplitude 200° C	Decreasing Wave Amplitude 300° C	Constant Wave Amplitude 100° C	Constant Wave Amplitude 200° C	Constant Wave Amplitude 300° C
⅝	.306	.305	41100	54000	62000	25400	33400	38600
¾	.441	.436	58800	77300	88800	36300	46500	55200
1	.785	.756	88500	116000	134000	62800	82800	95500
1⅛	.995	.92	124000	163000	187000	76700	100000	116000
1½	1.76	1.545	208000	273000	314000	129000	170000	196000
1¾	2.39	1.97	205000	348000	400000	176000	232000	267000
2	3.16	2.44	329000	432000	496000	202500	266000	307000

Where N is equal to a constant, as follows

For copper cable, N=10.1
For aluminum cable, N=6.45
For bare copper conductors, N=12.75
For bare aluminum conductors, N=8.1

Assuming K=.24 and f=.372, both of which will approximately meet the general circuit conditions, the formulas given above were used to obtain Table 3.

The above values are based on the assumption that no heat energy is dissipated and therefore will hold for insulated wires and coils as well as bare ductors. (See Table 4.)

Similar tables may be made up for studs and bars, provided due consideration is given to the current distribution by using the effective area in the calculations instead of the actual area. (See Table 5.)

For any time other than 1 second, multiply the current values in the tables by $\frac{1}{\sqrt{t}}$. For example, with a temperature rise of 200° C a one-inch stud will carry for 5 seconds a current of $82800\times\frac{1}{\sqrt{5}}=37000$ amp.

If it is desired to find the current for any other temperature rise, multiply the value of current in the above table for 100° C rise by C′ for 100° C rise and divide by C′ for the desired temperature and material. For example, with a one-inch stud and a temperature rise of 50° C, the current with constant wave amplitude is:

$$62800\times\frac{7.78}{10}=48900 \text{ amp.}$$

If on the other hand a one-inch aluminum stud were used with an allowed temperature rise of 50° C, the current with constant wave amplitude will be:

$$62800\times\frac{C'\,cu}{C'\,al}=62800\times\frac{7.78}{16.65}=29400 \text{ amp.}$$

By the use of the formulas and tables described in this article, it is possible to obtain a reasonably accurate indication of the temperature rise for any given conductor during transient periods or current surges of short duration.

VIEWS ON PATENT SYSTEM CHANGES*

By [illegible]

PATENT ATTORNEY . . . MILWAUKEE, WISCONSIN

The views expressed herein are those of the author and do not necessarily reflect the views of the editors of the ELECTRICAL REVIEW.

● Approximately one hundred and fifty years ago, this nation stood on the threshold of a new era, and the course was laid to transform it from a small agricultural country to the greatest and richest industrial nation in the world.

With uncanny foresight, the framers of the Constitution, consciously or otherwise, made this transition possible.

I have particular reference to Article One, Section 8, of the Constitution which reads, "Congress shall have the power to promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries."

It is unfortunate that the framers of the Constitution did not live to realize or appreciate the importance of the patent section thereof.

● First patent law

Under the authority of Article One, Section 8, of the Constitution, Congress enacted the first patent law, known as the Act of April 10, 1790. This Act provided for the issuance of patents by the Secretary of State, the Secretary of the Department of War, and the Attorney General, if any two of them deemed the invention or discovery sufficiently useful and important. The patents were issued for a term of fourteen years.

The first inventor to avail himself of the advantages of the Act of April 10, 1790, was Samuel Hopkins, to whom Letters Patent were issued July 21, 1790, for a "Process of Making Pot and Pearl Ashes."

Various amendments were made to the Act of 1790 in 1793, 1794, 1800, and 1819. In 1836 all of the various amendments were combined into a single act which, except for minor changes, remains substantially unchanged.

The citizens of this predominantly agricultural nation were slow to appreciate the advantages and possibilities afforded by the patent laws. The number of patents granted under the laws existing prior to 1836 did show a gradual increase each year, and it is interesting to note that in 1833, when a total of five hundred and eighty-six (586) patents were issued, one of the six employees of what might be said to have constituted the Patent Section of the Secretary of State's Office resigned because, in his opinion, "everything inventible has been invented, and in a few years the doors of the office will close."

● The Act of 1836

The Act of 1836, which was approved July 4 of that year, established for the first time what is now known as the Patent Office and provided a Commissioner of Patents, a Chief Clerk, an Examining Clerk, three other clerks (one of whom was to be a competent draftsman), a machinist, and a messenger.

Under the protection afforded, inventors of new, novel, and useful processes, mechanisms, machines, etc., inventive genius has been stirred to create the things which make possible the comforts and conveniences enjoyed today. Also, these laws encouraged men to invest not only the work of their creative minds but their savings to promote the production of these creations because of the monopoly given. As a result, we have in this country a large number of corporations who owe their very existence to the issuance of some one or more patents, and without which our country would soon become nothing more than a backward state.

In support of this statement, attention is called to well-known companies, each of which employs thousands of men and pays millions of dollars yearly into the Federal and State Treasuries. A few of these, which readily come to mind, are:

Goodyear Tire & Rubber Company
Singer Sewing Machine Company
The Pullman Company
Thomas A. Edison, Inc.
L. E. Waterman Company
Burroughs Adding Machine Company
Eastman Kodak Company
Aluminum Company of America
Carborundum Company
Gillette Safety Razor Company

* Summary of talk given before American Society of Mechanical Engineers, May 26, 1938.

• Monopoly and reward

Essentially, a patent is a monopoly in the strictest sense of the word, but at the same time it is a reward offered as an inducement to the exercise of creative genius. During recent years, monopolies have fallen into disrepute, and unfortunately those in high places have not seen fit to distinguish between the just rewards for creative effort (as contemplated by the framers of the Constitution) and monopolies born out of unscrupulous use of wealth. As a result, all monopolies have been stamped as bad, and patents have been posed as the underlying evil. Unfortunately, therefore, a studied attempt is being made to nullify and wreck the patent system.

To this end, Representative McFarlane of Texas, following the President's speech on monopolies the first part of this year, introduced House Office Bill 9259, which provides that, after three years, anyone may apply to the Commissioner of Patents for a license under any patent, and that the Commissioner of Patents will then conduct a hearing to determine whether the applicant is an interested party, financially responsible and able to manufacture such patent to supply the market.

The McFarlane bill, instead of lessening monopolistic evils, works to the contrary. Frequently the sole protection of the smaller company against its larger competitor, with greater manufacturing and selling facilities, is its patents. The bill fails to take into consideration the thousands of dollars that may have been spent during the first years of a patent, which are generally devoted solely to preparing the invention for commercial use. Then the patentee is subjected to competition, and before he has been reimbursed for the actual money spent — much less rewarded for his creative ability — many years may have elapsed.

At the hearings conducted by the House patent subcommittee, headed by Mr. O'Malley, last March, on the McFarlane and two other bills, which will be referred to later, the sole argument offered in support thereof was a reading of that portion of the President's speech of January pertaining to monopolies, wherein he dealt broadly with the patent system, and the unsupported statement that it was being used by large corporations to the disadvantage of the public.

• H. R. 10068

A number of patent lawyers and manufacturers appeared before the subcommittee and testified that the proposed bills would wreck one of the very things that made our country the leading nation. Since these hearings, the feeling has prevailed that nothing would come of the McFarlane bill. However, those who are close to the matter in Washington feel quite the contrary. A substitute bill, H. R. 10068, has been offered by Mr. McFarlane, which differs from the first mainly in that it gives the inventor the exclusive right for a period of five years, after which, "where satisfactory evidence is submitted showing that a patent is not being used, or that domestic supply is insufficient to satisfy the public demand, or that unfair prices or trade practices prevail," any person may make application for a license.

• H. R. 9815

H. R. 9815, introduced by Mr. Connery, provides that when any two persons or companies, each holding patents and in competition with each other, grant cross-licenses, these shall then be subject to application for licenses. In other words, if two concerns manufacture competing patented articles which infringe the patents of each other, they are penalized if, instead of indulging in lengthy and costly litigation, they settle their controversy by cross-licensing. Therefore, by being sound and sane business men, they lay themselves open to further needless competition and destroy all possible protection such as is now offered by our Patent System.

• H. R. 1666

A third and very vicious bill considered by the subcommittee is H. R. 1666, offered by its chairman, Thomas O'Malley of Milwaukee. This proposed law would place the government treasury at the disposal of indigent patentees to harass the legitimate manufacturer. All the indigent patentee need do is appear before the Federal Judge in the District in which he resides and take a pauper's oath. The Court then must certify the matter to the Commissioner of Patents who, after consideration of the very incomplete information available to him, if he finds the cause to be meritorious, appoints a lawyer "experienced" in patent-law practice to represent the patentee. This lawyer shall be paid out of the public treasury at the rate of Fifty Dollars ($50.00) per day for time spent in the Court and in the preparation, in addition to all travel expenses, etc.

The evident result, should this bill be written into the statutes, would be the immediate harassment of corporations by all patentees believing they had a law suit and would be the means of placing an undue penalty on these companies to defend their rights to remain in business, with the resources of the Federal Government against them.

Supported by the record of the past 150 years, the Patent System of the United States has proved itself beyond all doubt. In my opinion, it has helped as much as any other single factor to advance this country from a small agricultural nation to the greatest and richest industrial nation in all the world.

Let us not tear down what has been so adequately built up for us. Let us rather preserve for the future at least what we had to start with, and, if possible, improve it to the best of our ability.

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